The C-Train:
Highlights of A-Train Contributions to Carbon Cycle Science

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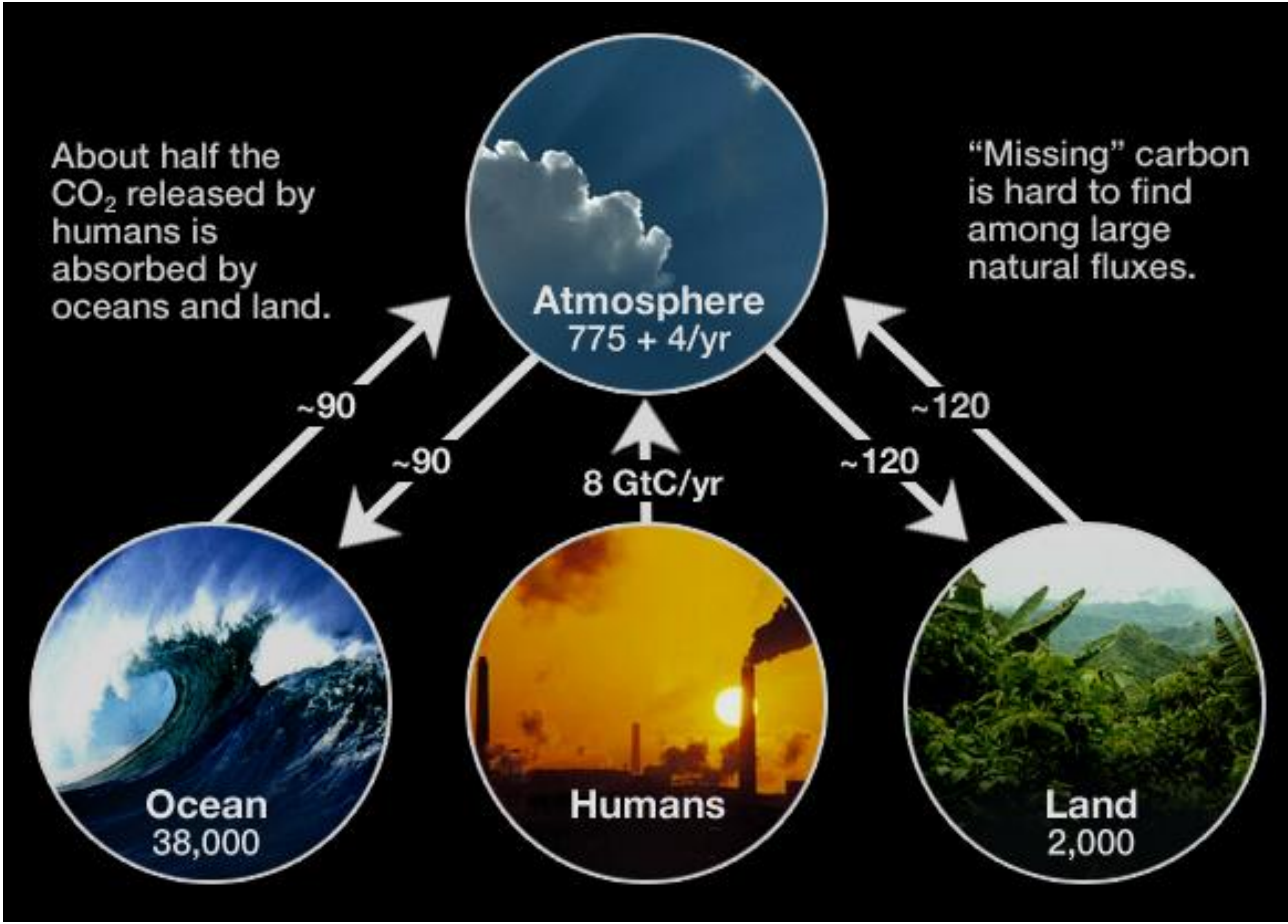
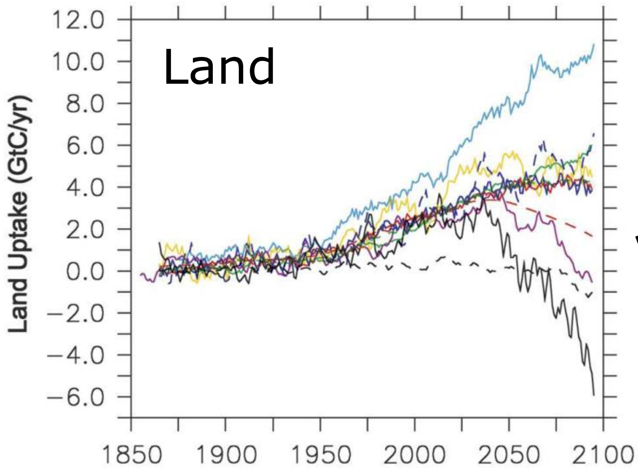
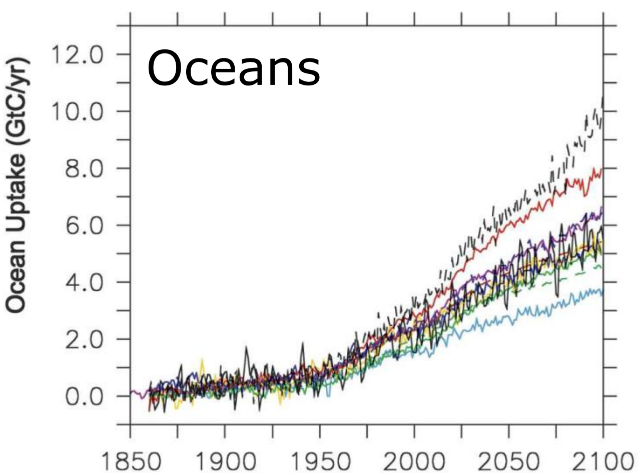
Contributors: Mous Chahine, David Crisp, Nancy French, Deborah Huntzinger, Dylan Jones, Eric Kasischke, Chip Miller, Ray Nassar, Ed Olsen, Tom Pagano, Steve Running

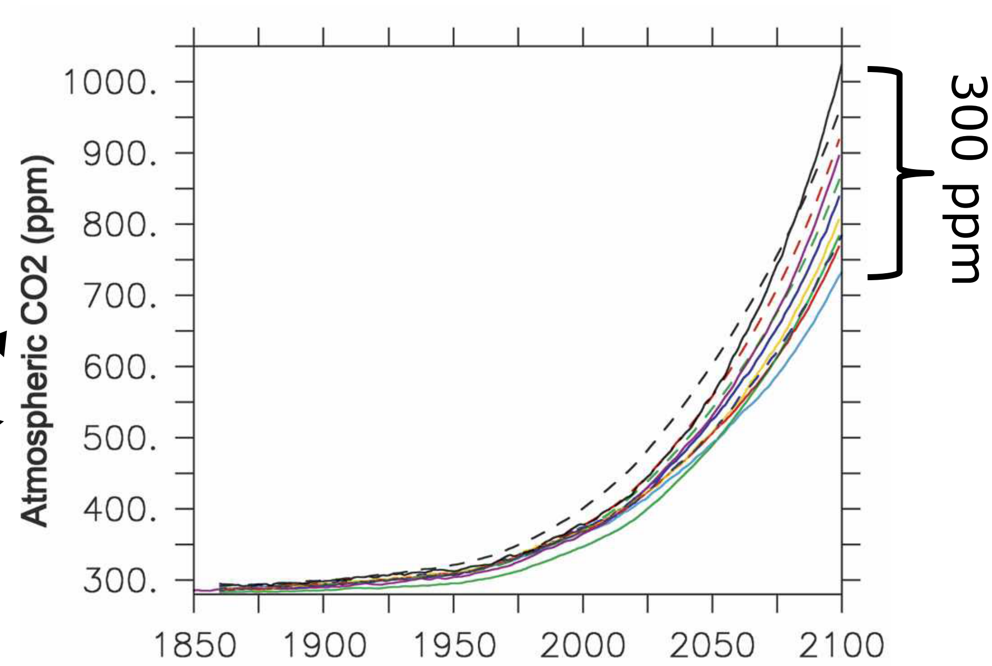

About half the CO_2 released by humans is absorbed by oceans and land.
"Missing" carbon is hard to find among large natural fluxes.
Atmosphere
775 + 4/yr
~90
~90
8 GtC/yr
~120
~120
Ocean
38,000
Humans
Land
2,000

The Future of Natural Carbon Sinks





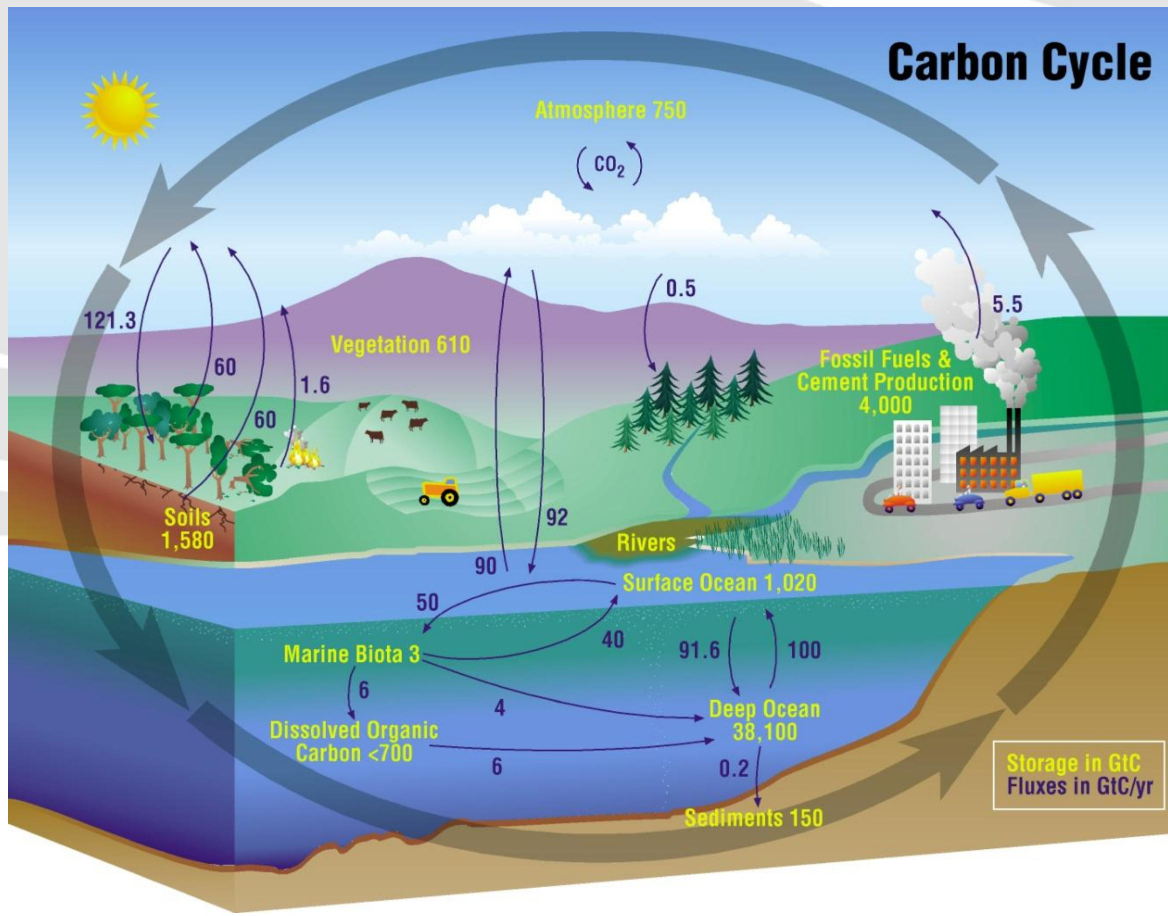
Uncertainty associated with the future of natural carbon sinks is one of two major sources of uncertainty in future climate projections



Source: Friedlingstein et al. (2006) showing projections from coupled carbon and climate simulations for several models.

NASA Carbon Cycle Research

Goal: To improve understanding of the global carbon cycle and to quantify changes in **atmospheric CO_2 and CH_4 concentrations** as well as **terrestrial and aquatic carbon storage** in response to fossil fuel combustion, land use and land cover change, and other human activities and natural events.



Source: Diane Wickland

NASA'S Carbon-Measuring Satellites

- **Satellites Currently in Orbit:**

Aqua	**Landsat-7**	**EO-1**
Aura	**Terra**	**ICESat** (just failed)
	Aqua	**QuikSCAT** (just failed)
	SeaWiFS	

- **Missions in Formulation and Implementation:**

OCO-2	**LDCM**	**SMAP**
	NPP	
	ICESAT-2	

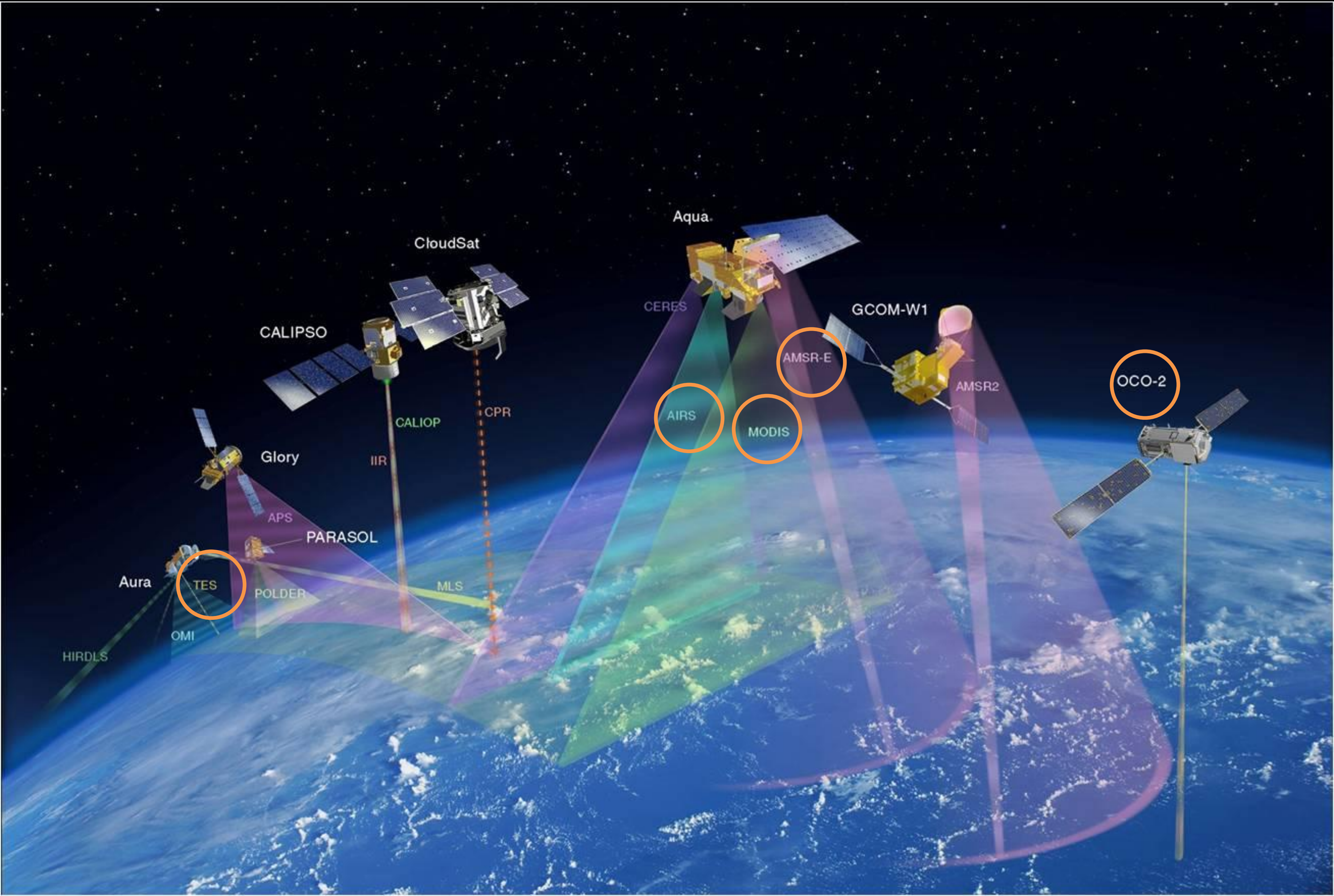
- **Decadal Survey Missions:**

ASCENDS	**DESDynI**	**SMAP**
	ICESat-2	**SCLP**
	HyspIRI	
	ACE	
	GEO-CAPE	
	LIST	

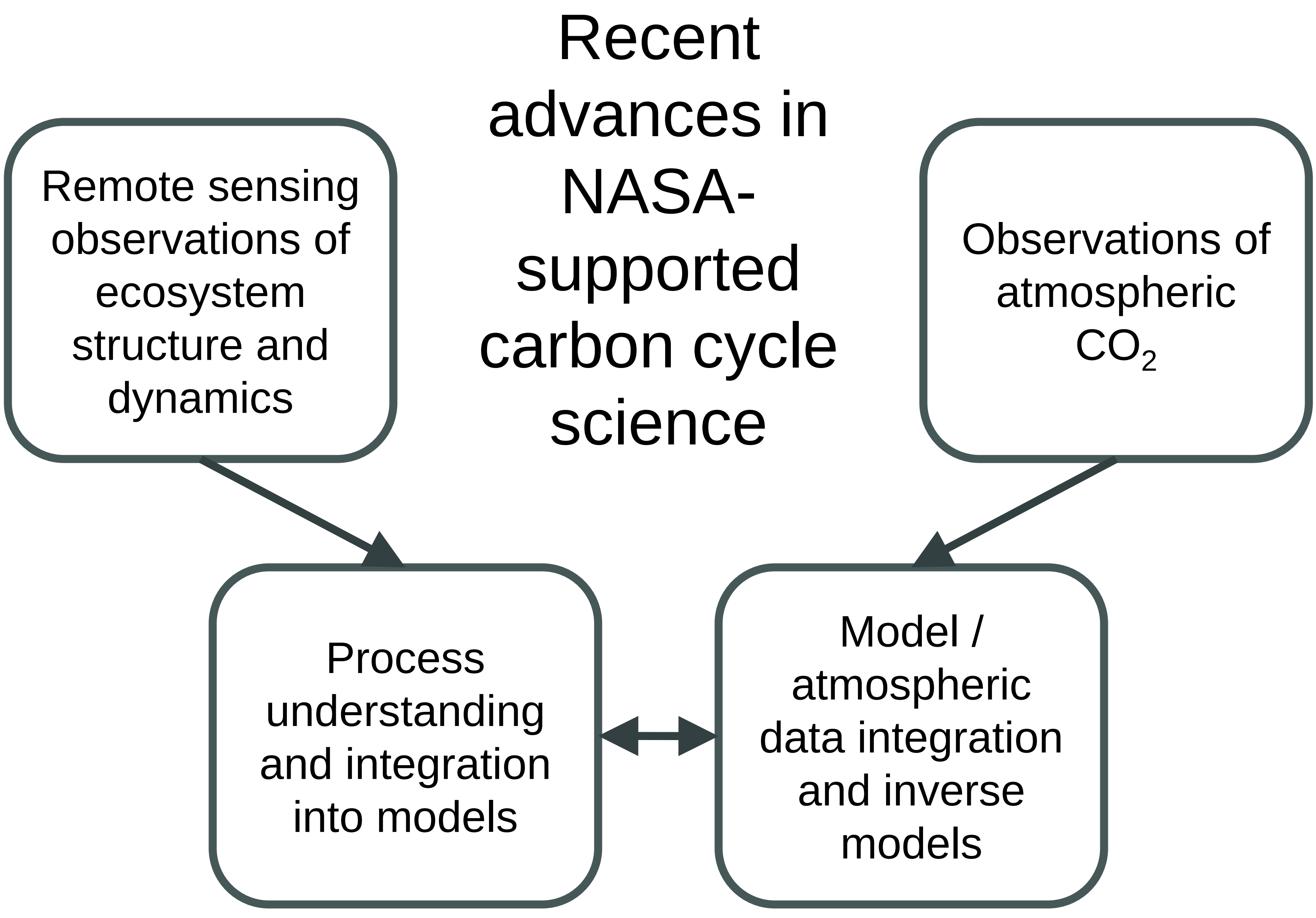
Greenhouse Gases
Carbon Stocks
Supporting Observations

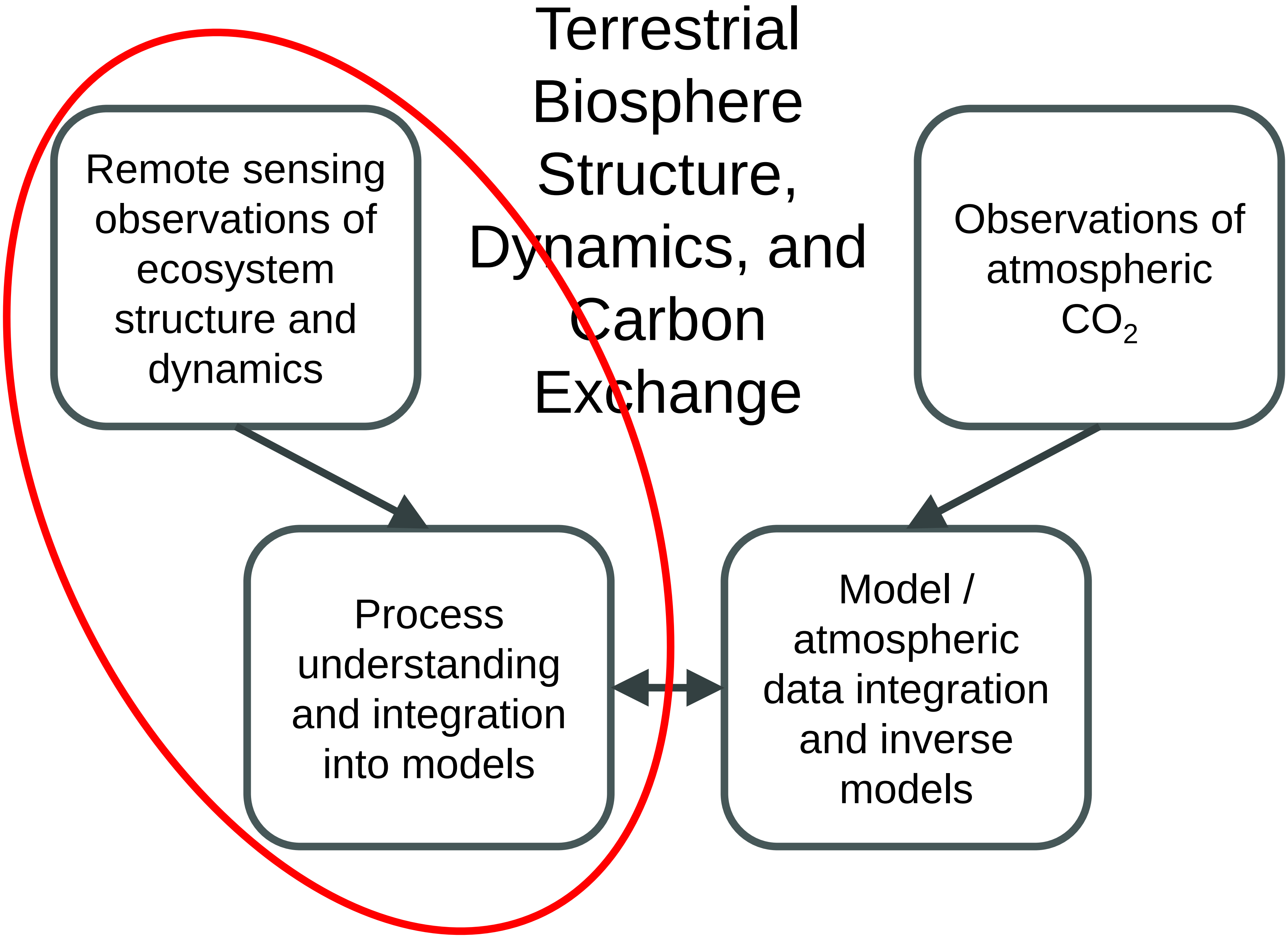
Source: Diane Wickland

The A-Train



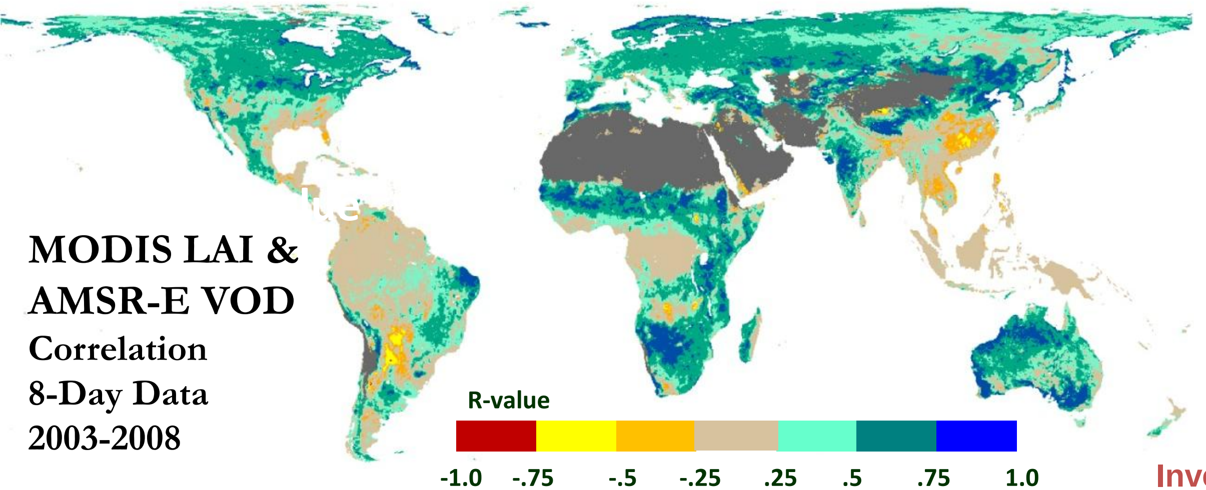
Aqua
CloudSat
CERES
GCOM-W1
CALIPSO
AMSR-E
OCO-2
AMSR2
AIRS
MODIS
CPR
CALIOP
Glory
IIR
APS
PARASOL
Aura
TES
POLDER
MLS
OMI
HIRDLS


Recent advances in NASA-supported carbon cycle science
Remote sensing observations of ecosystem structure and dynamics
Observations of atmospheric CO_2
Process understanding and integration into models
Model / atmospheric data integration and inverse models



Terrestrial Biosphere Structure, Dynamics, and Carbon Exchange
Remote sensing observations of ecosystem structure and dynamics
Observations of atmospheric CO_2
Process understanding and integration into models
Model / atmospheric data integration and inverse models

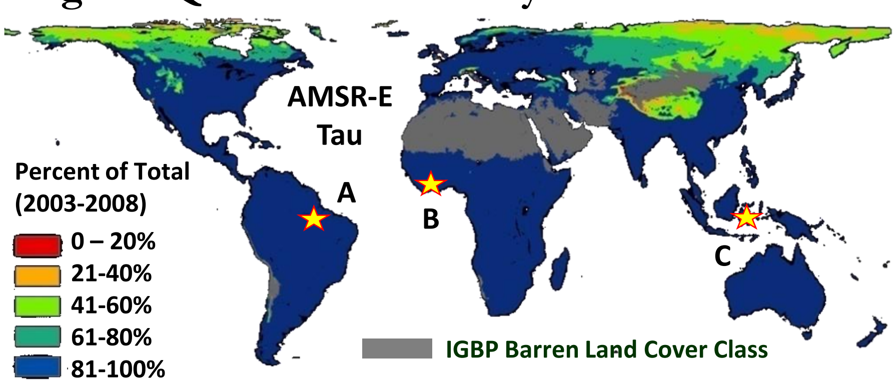
Global Phenology Monitoring using Vegetation Optical Depth (VOD) from AMSR-E

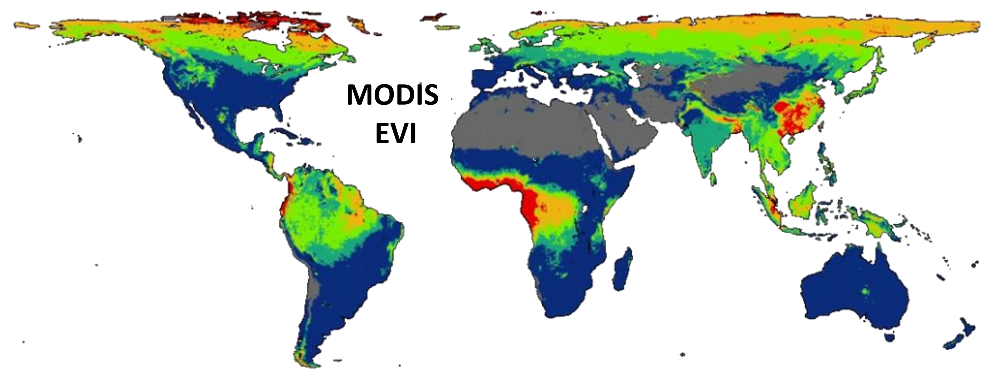


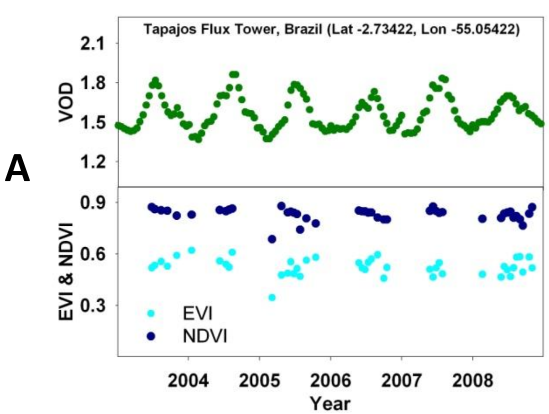
- AMSR-E VOD (10.65GHz) is well correlated with MODIS LAI, EVI and NDVI
- Microwave provides enhanced data availability, especially over cloud dominated regions, resulting in complete vegetation phenologies when optical-IR VIs are unavailable or saturated
- AMSR-E VOD provides a unique and complementary phenology dataset.

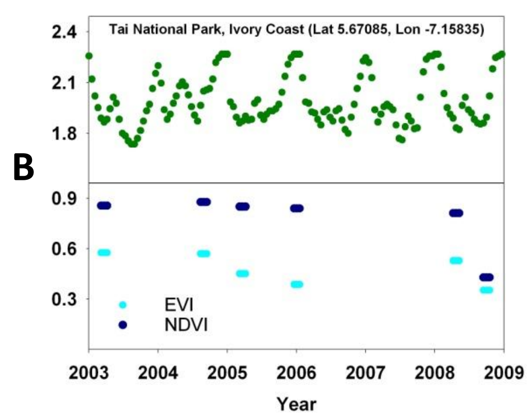
Investigators: J. Kimball, M. Jones, K. McDonald

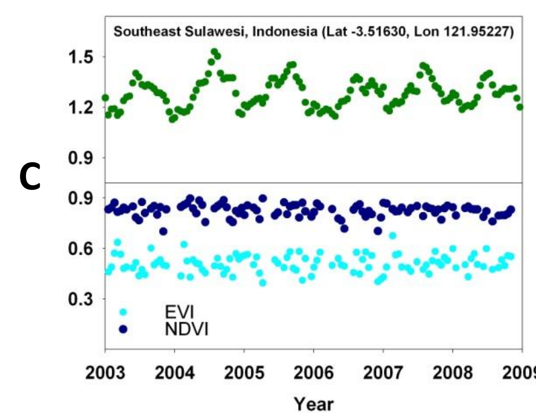
Highest QC Data Availability



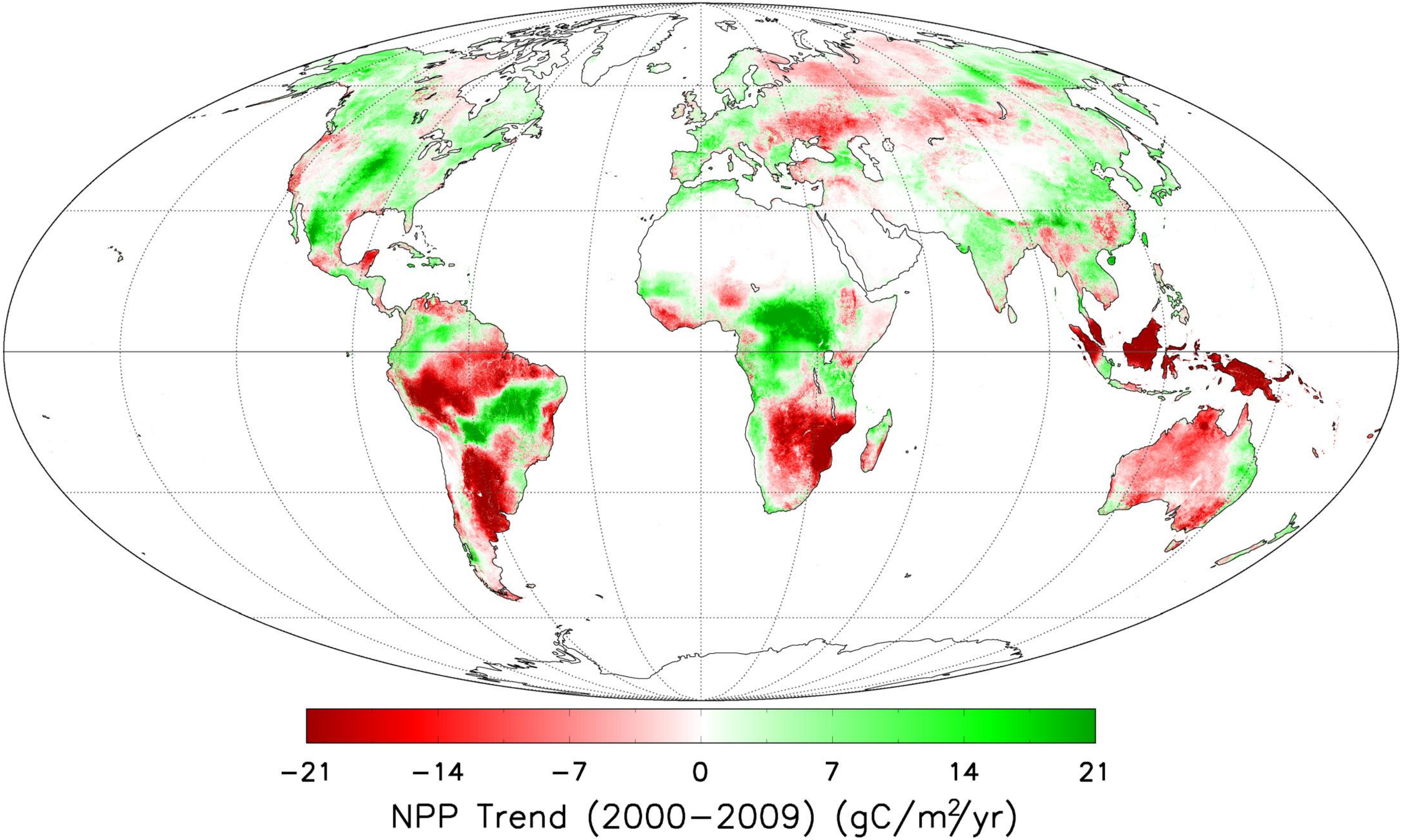






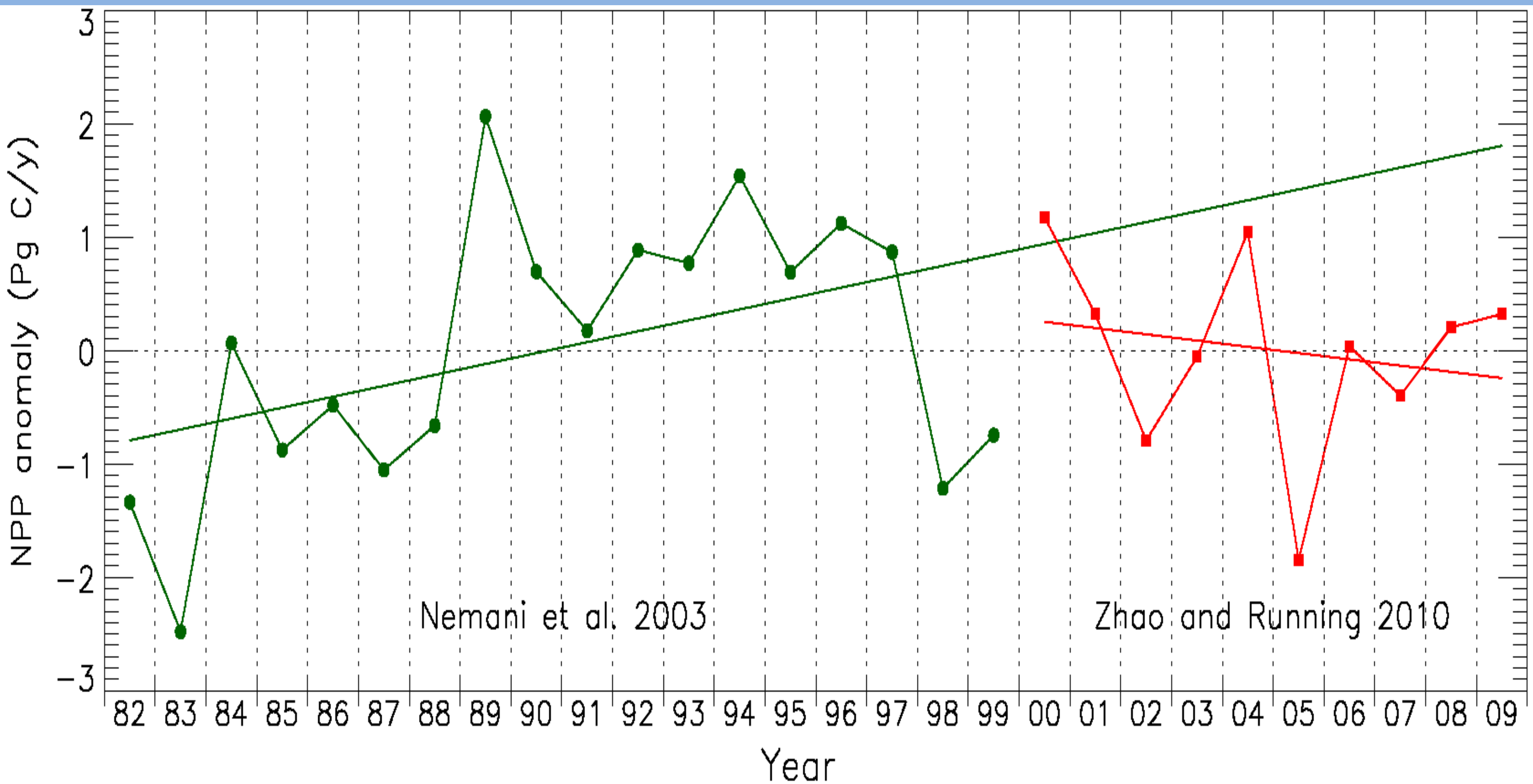


NPP trend (2000-2009)

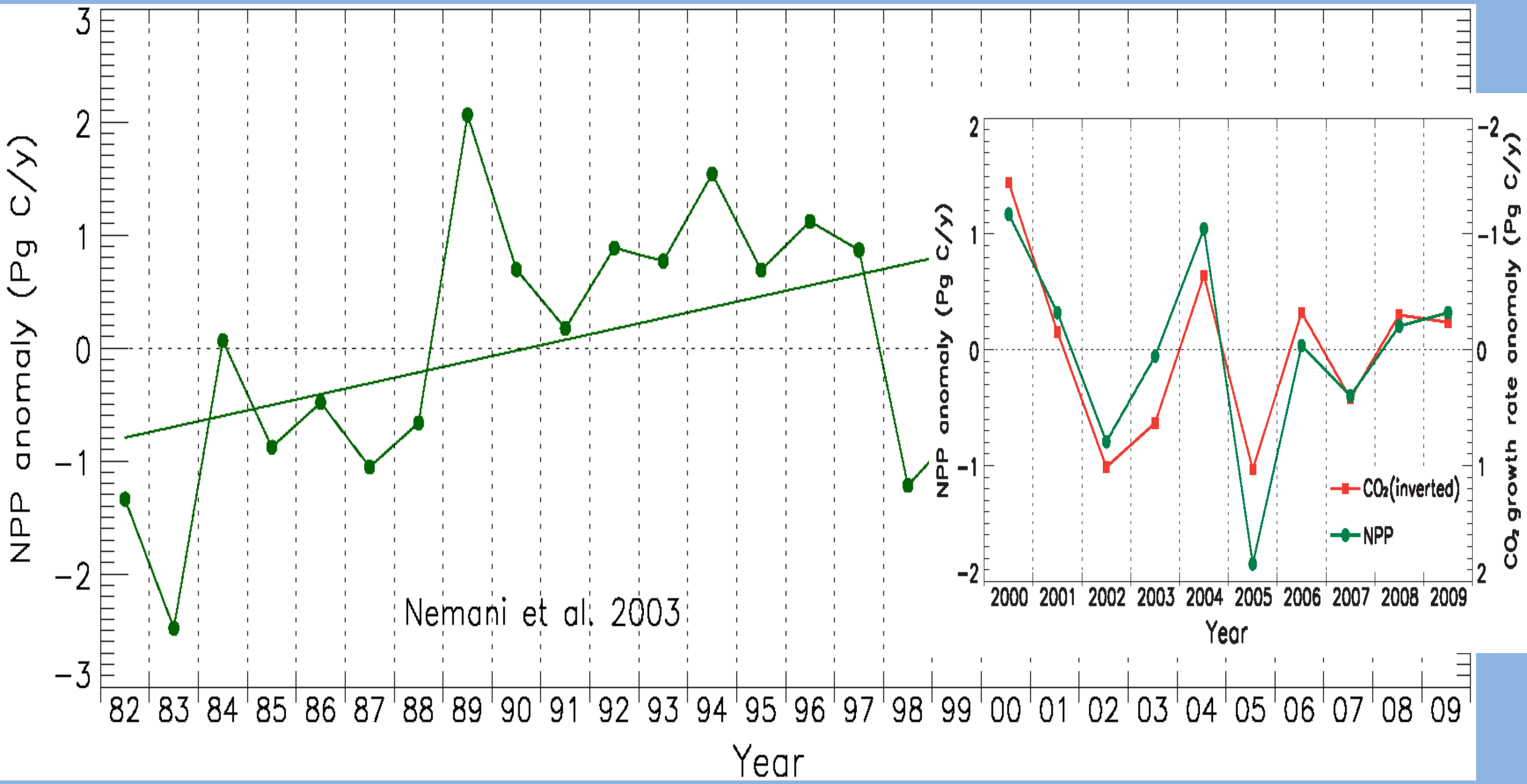


Zhao & Running 2010, *Science*

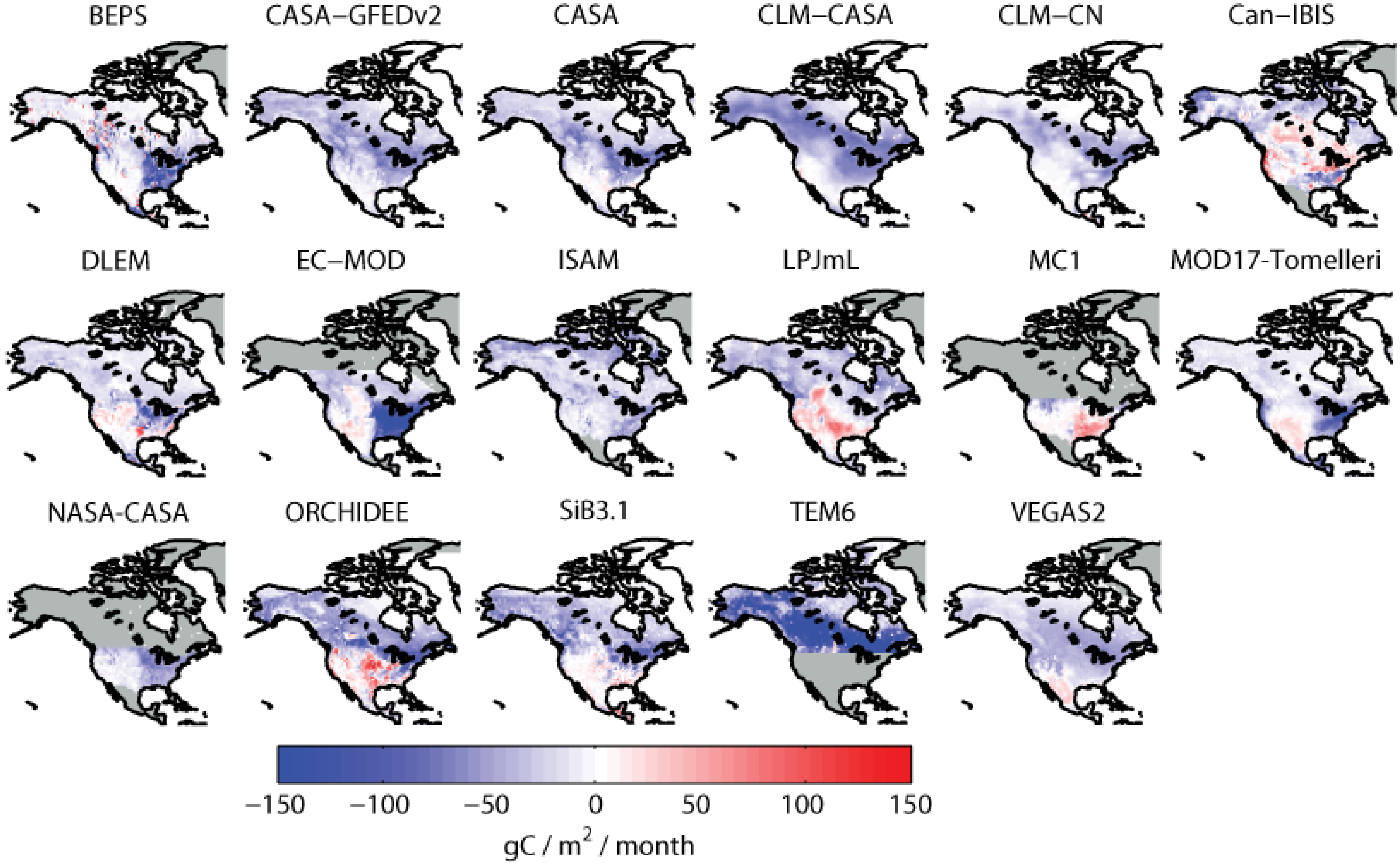
Remotely Sensed NPP change (1982-2009)



Remotely Sensed NPP change (1982-2009)



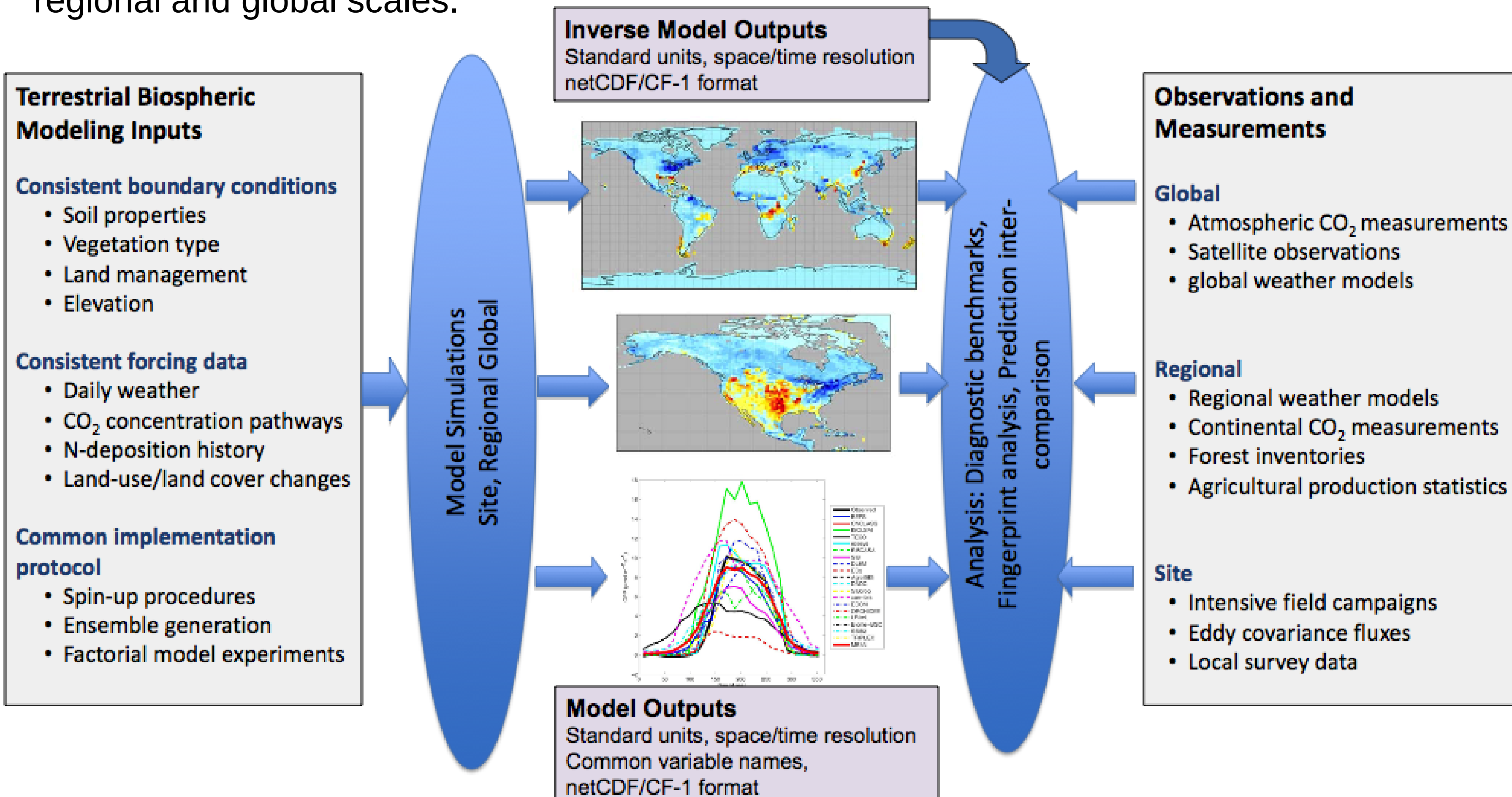
Biospheric Models as Priors



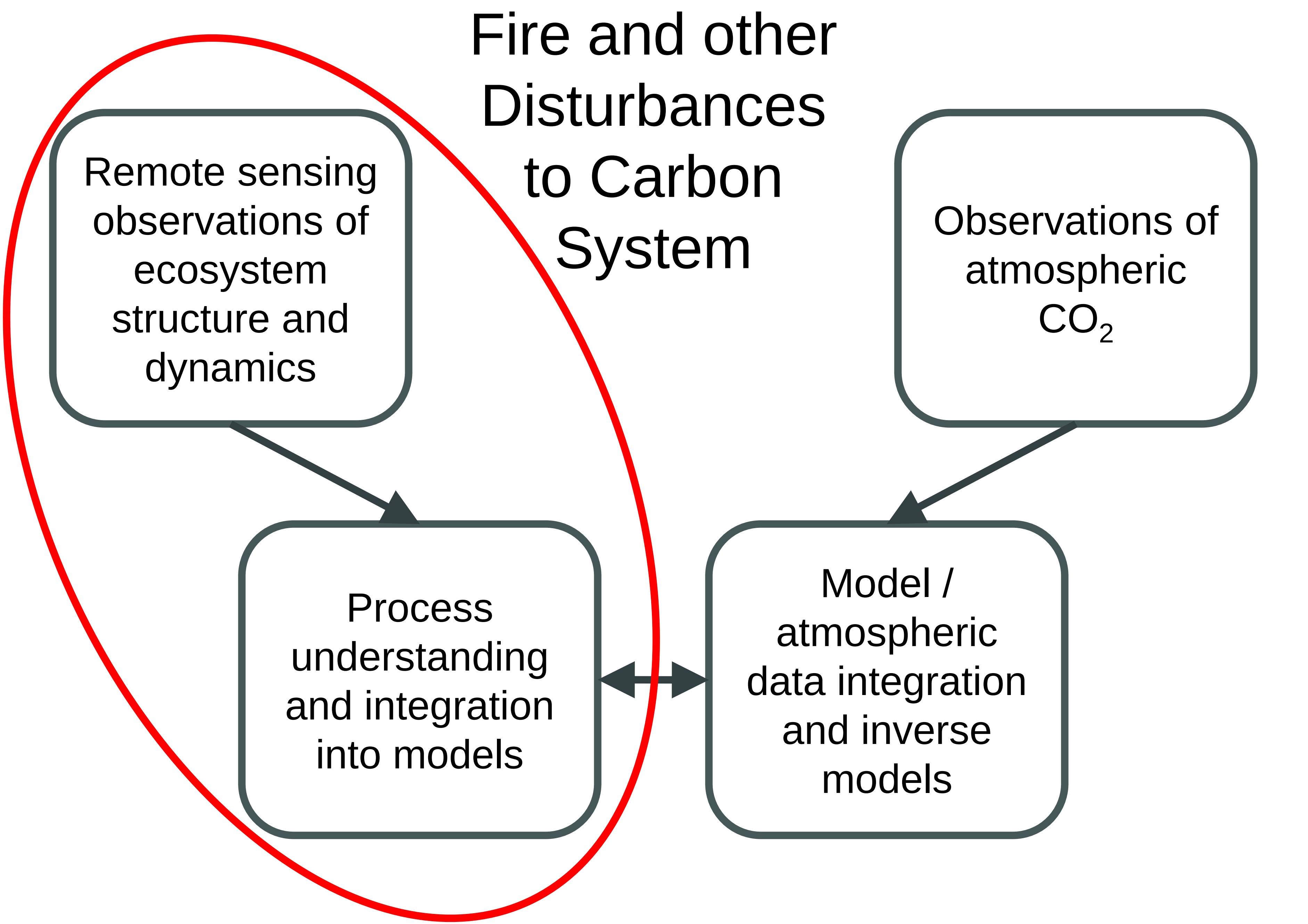
Source: Deborah Huntzinger, U. Michigan

Multi-Scale Synthesis and Terrestrial Model Intercomparison Project (MsTMIP)

The goal of the MsTMIP is to provide feedback to the terrestrial biospheric modeling community to improve the diagnosis and attribution of carbon sources and sinks across regional and global scales.



Deborah Huntzinger (Sci-PI), Anna Michalak (PI),
Bob Cook, Andy Jacobson, Mac Post, Kevin Schaefer



Fire and other Disturbances to Carbon System
Remote sensing observations of ecosystem structure and dynamics
Observations of atmospheric CO_2
Process understanding and integration into models
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Detecting Disturbances in Global Forest Cover – MODIS 2000 to 2008

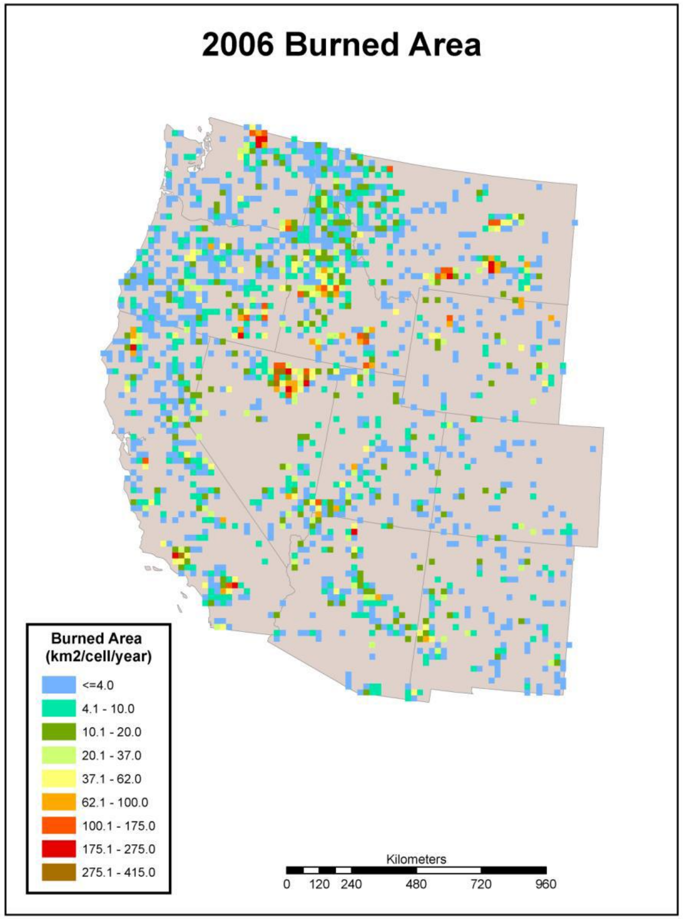
Reference: Potter, C., S. Boriah, M. Steinbach, V. Kumar, and S. Klooster. 2008. Terrestrial vegetation dynamics and global climate controls in North America: 2001-2005. *Earth Interactions*, 12: 1-12.

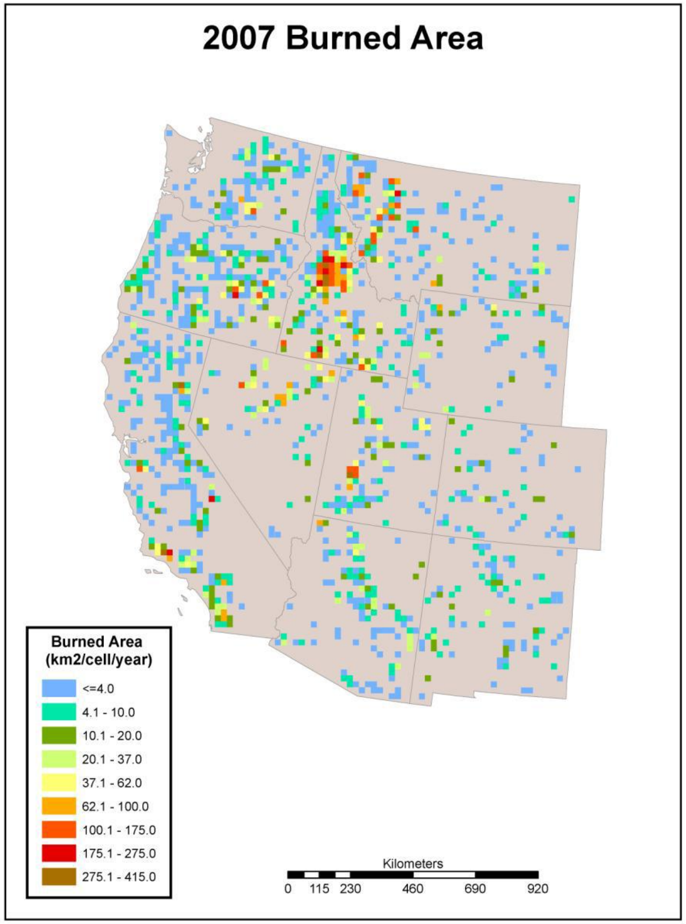
MODIS EVI Time Series, 4-km Resolution

Plot Above:
Detection of Basin Fire
97,000 hectares
Big Sur, CA
June-July 2008

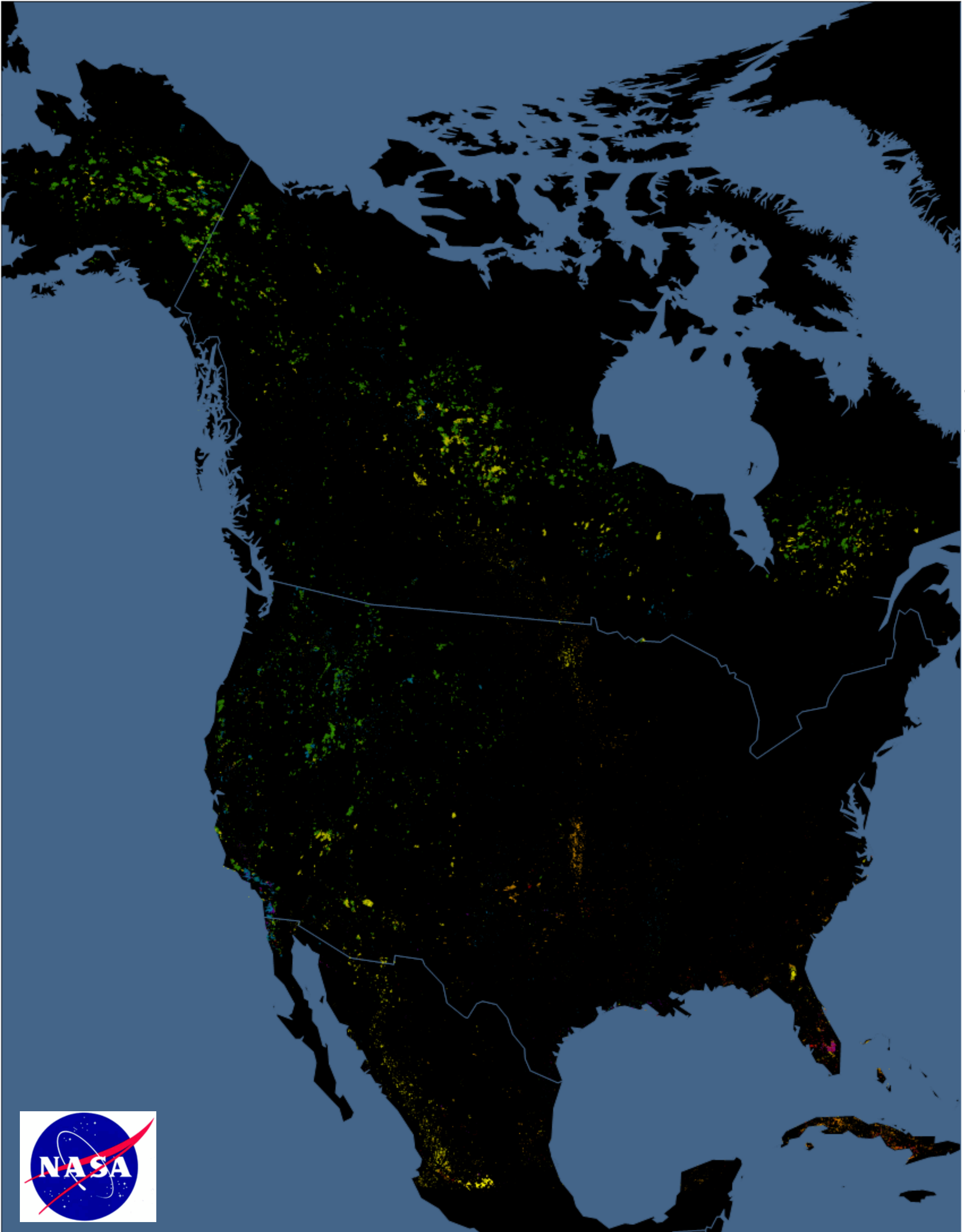
Ames Research Center

Annual MODIS Observed Burned Area





Urbanski and Hao, US Forest Service



Burn Area for North America

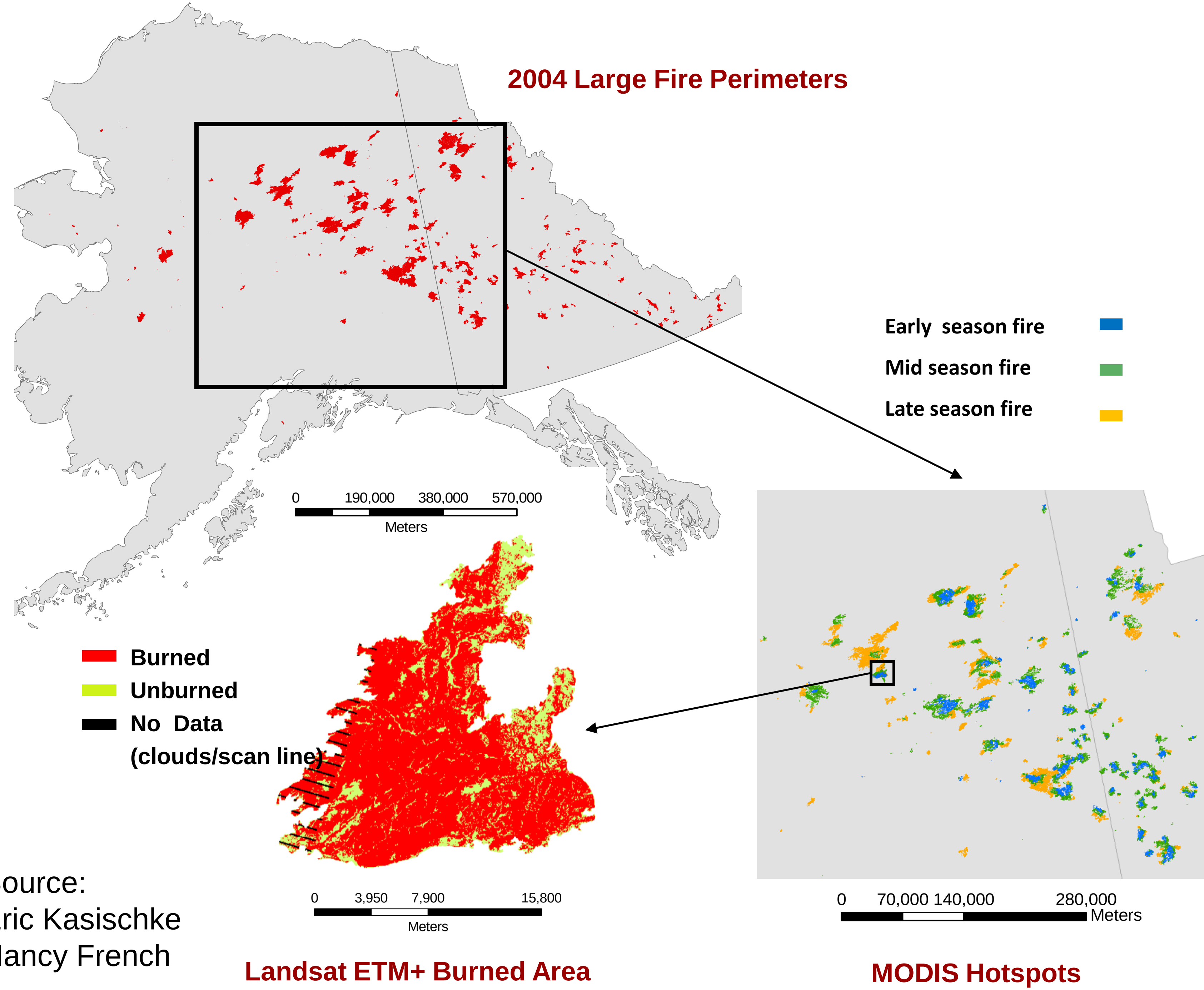
MODIS Direct Broadcast Burned Area Product (DBBAP)*

2001 - 2009

Burn date

- Jan - Feb.
- March - Apr.
- May - June
- July - Aug.
- Sept. - Oct.
- Nov. - Dec.

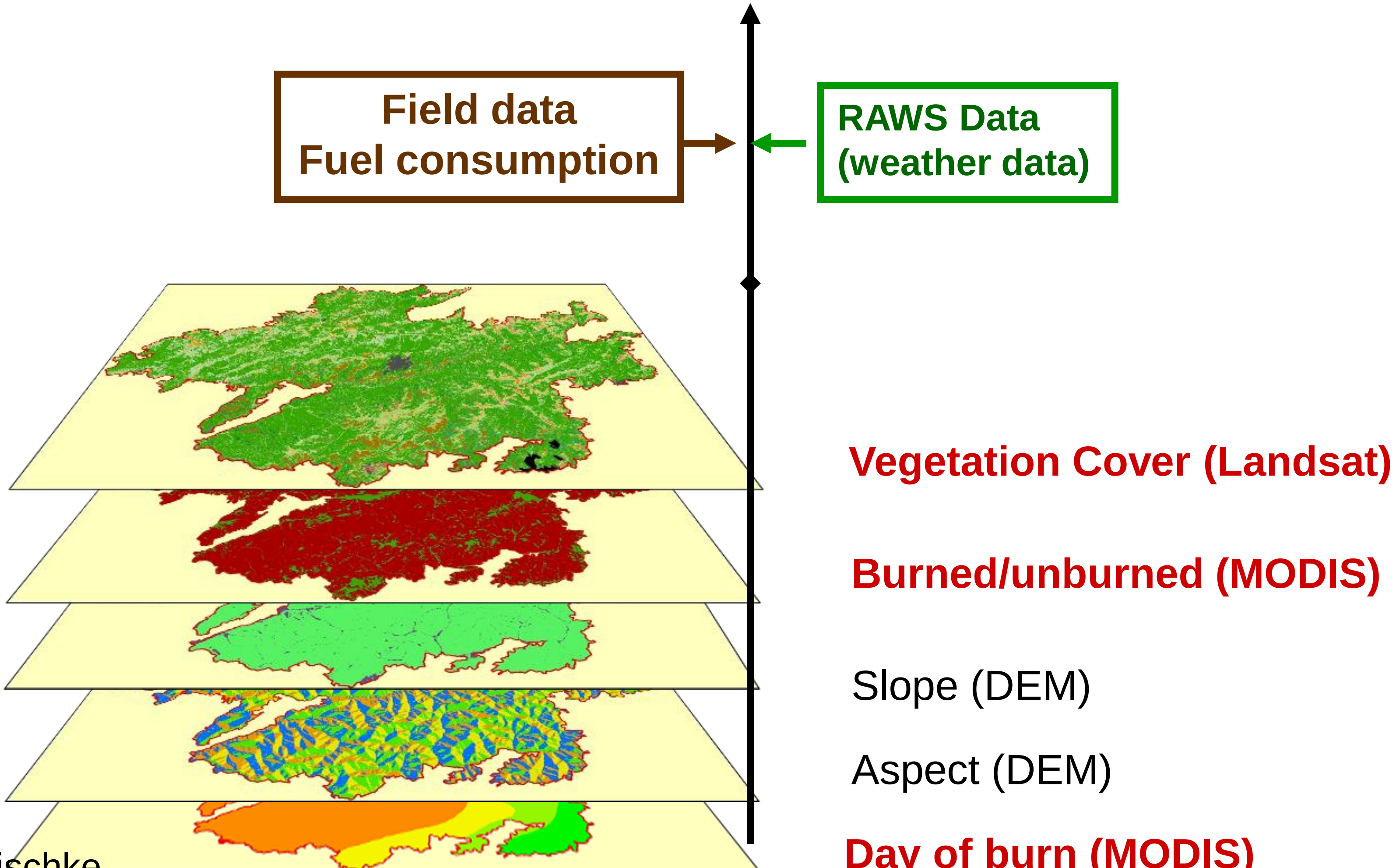
*Giglio, L. et al. 2009 *Rem. Sens. Environ.*, 113(2), 408-420



Source:
Eric Kasischke
Nancy French

Emissions from 2004 Alaskan Fires

BORFIRE-AK **39.9 Tg C**
GFED2 **19.3 Tg C**



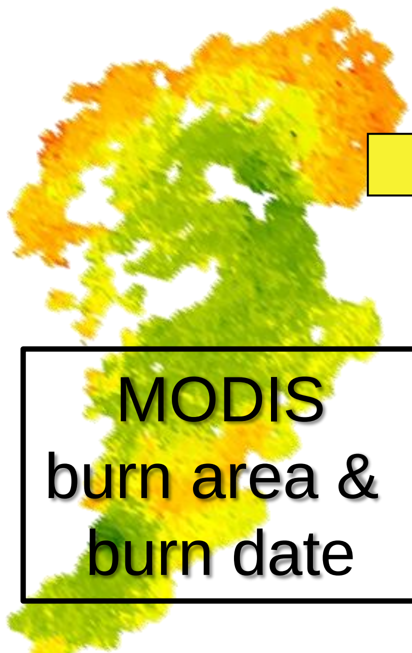
Source:
Eric Kasischke
Nancy French

MichiganTech Research Institute

Biomass Burning Emissions Estimates Using WFEIS

Wildland Fire Emissions Information System (WFEIS) is an online geospatial tool for North American fire emissions estimation *http://wfeis.mtri.org/*

WFEIS Example: 2002 Biscuit Fire, southeastern Oregon, Burned Area = 1,696 km^2



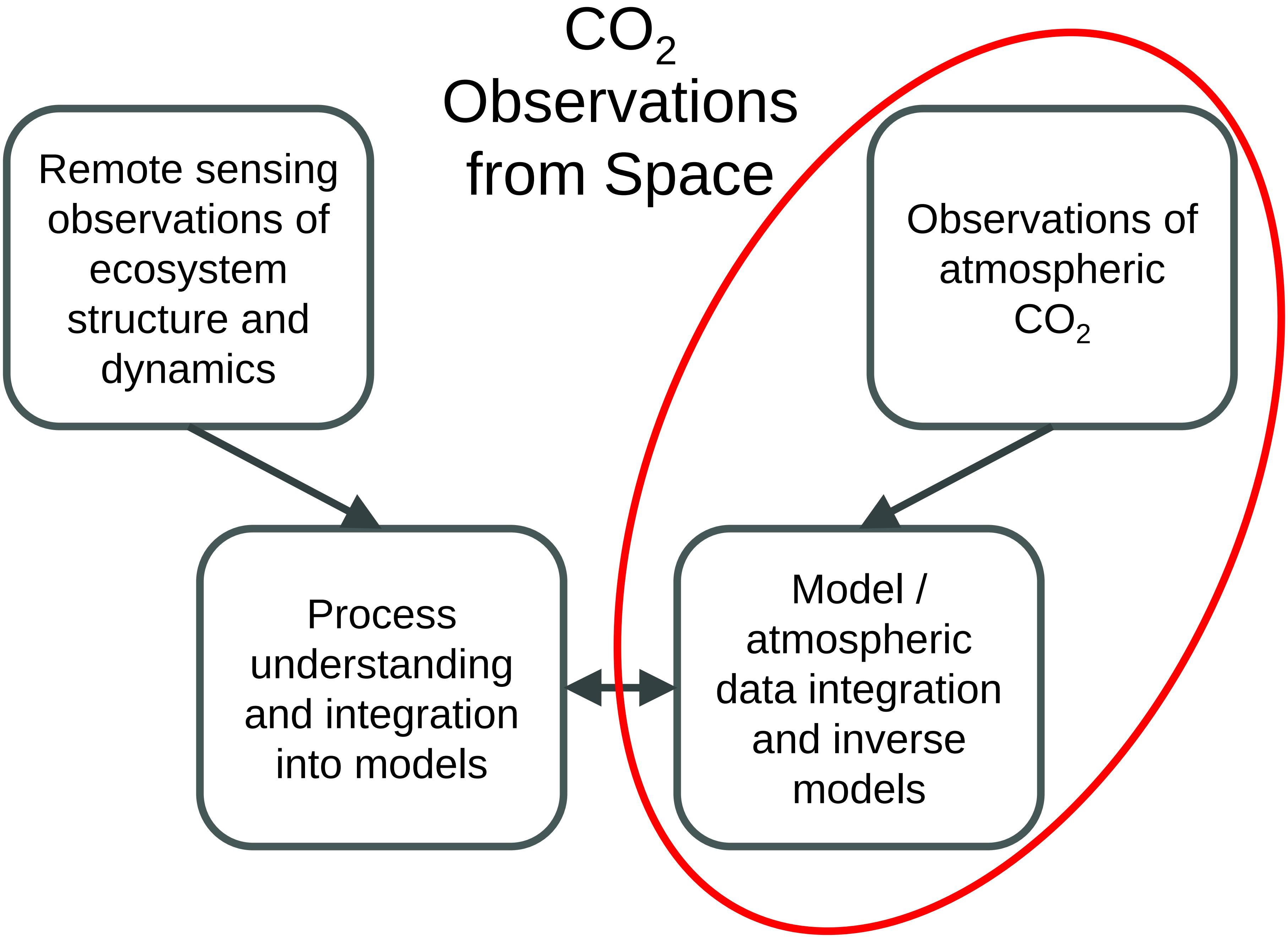
MODIS burn area & burn date

WFEIS model:
- *Mapped vegetation*
- *% consumption (from weather)*

Total Carbon Emissions
5.2 x10^9 kg

Area Normalized Carbon Emissions
3.1 kg-C/m^2

Source: Nancy French


CO_2 Observations from Space
Remote sensing observations of ecosystem structure and dynamics
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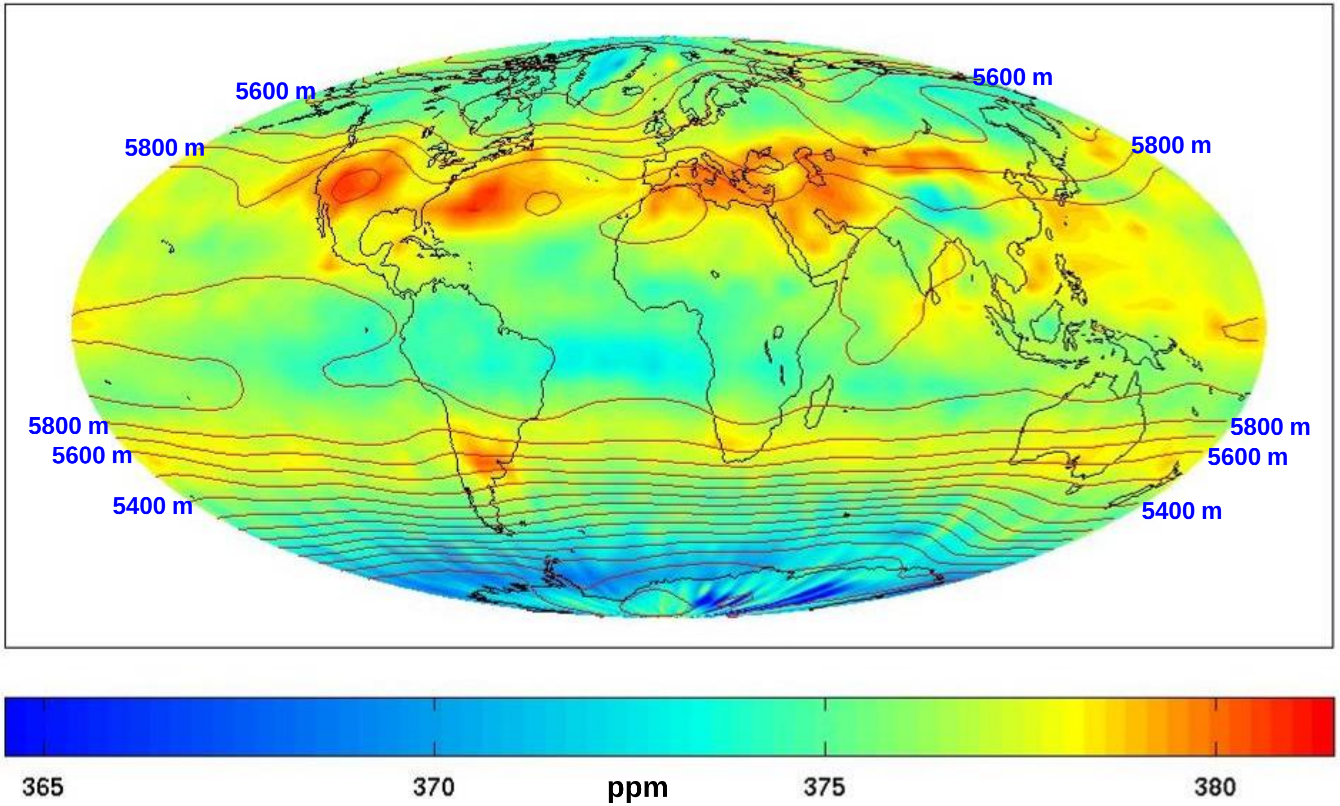
8 Years of AIRS Mid-Trop CO2 Data

Day/Night, Pole-to-Pole, Land/Ocean/Ice, Cloudy/Clear

July 2003 AIRS mid trop CO_2 (5° smoothing) with 500 hPa gph contours overlaid



- **CO_2 is not well mixed in Mid-Troposphere**
- **Complexity of the CO2 in SH not present in models**

Source: Tom Pagano, Mous Chahine, Ed Olsen

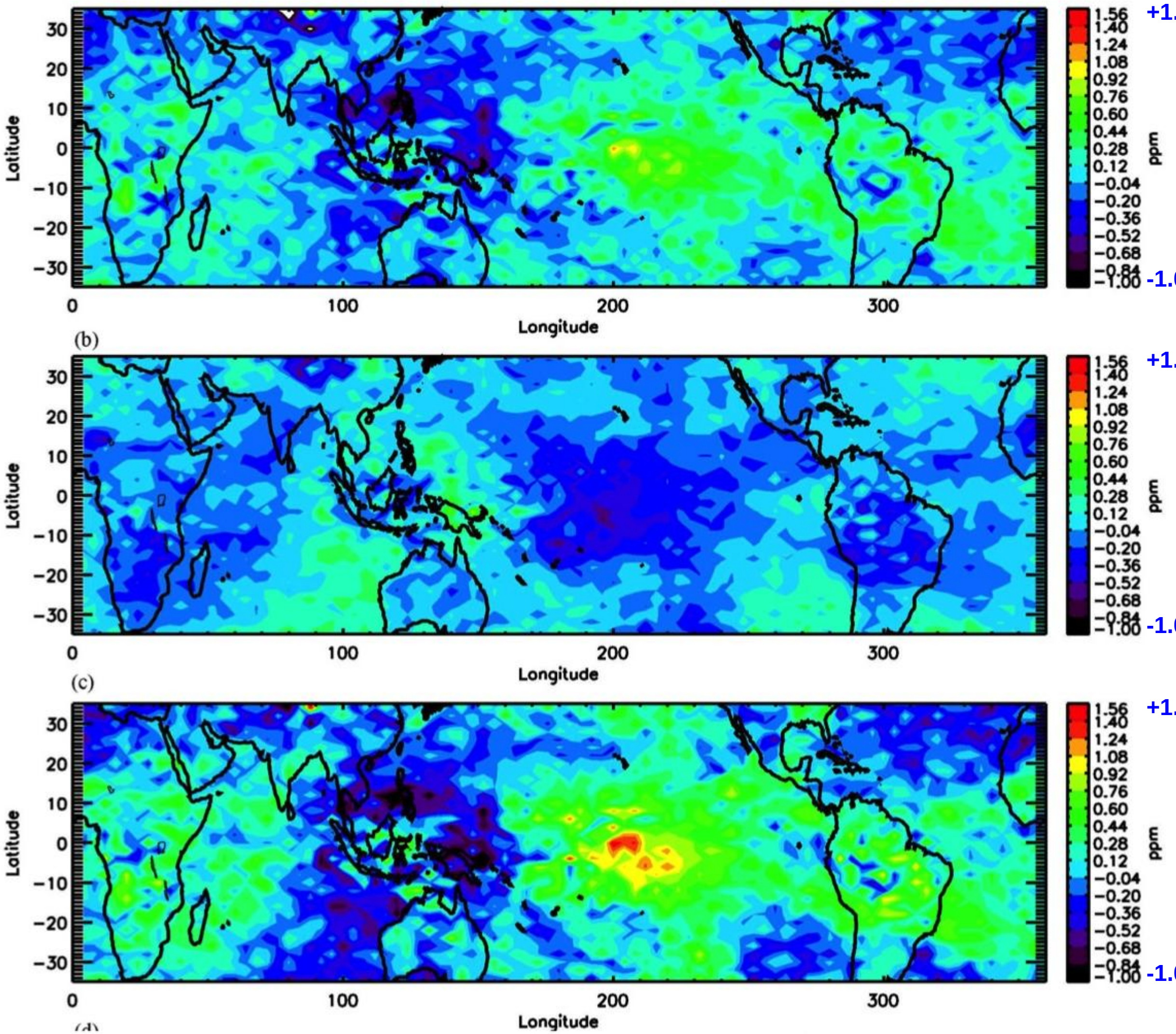
National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Atmospheric Infrared Sounder

Influences of El Niño in Mid-Trop CO2 Agrees with Walker Circulation

(Xun Jiang, University of Houston)



+1.56 ppm

-1.00 ppm

AIRS detrended and deseasonalized CO_2 anomaly averaged for 11 El Nino months

(High CO2 in Central Pacific)

+1.56 ppm

-1.00 ppm

AIRS detrended and deseasonalized CO_2 anomaly averaged for 17 La Nina months

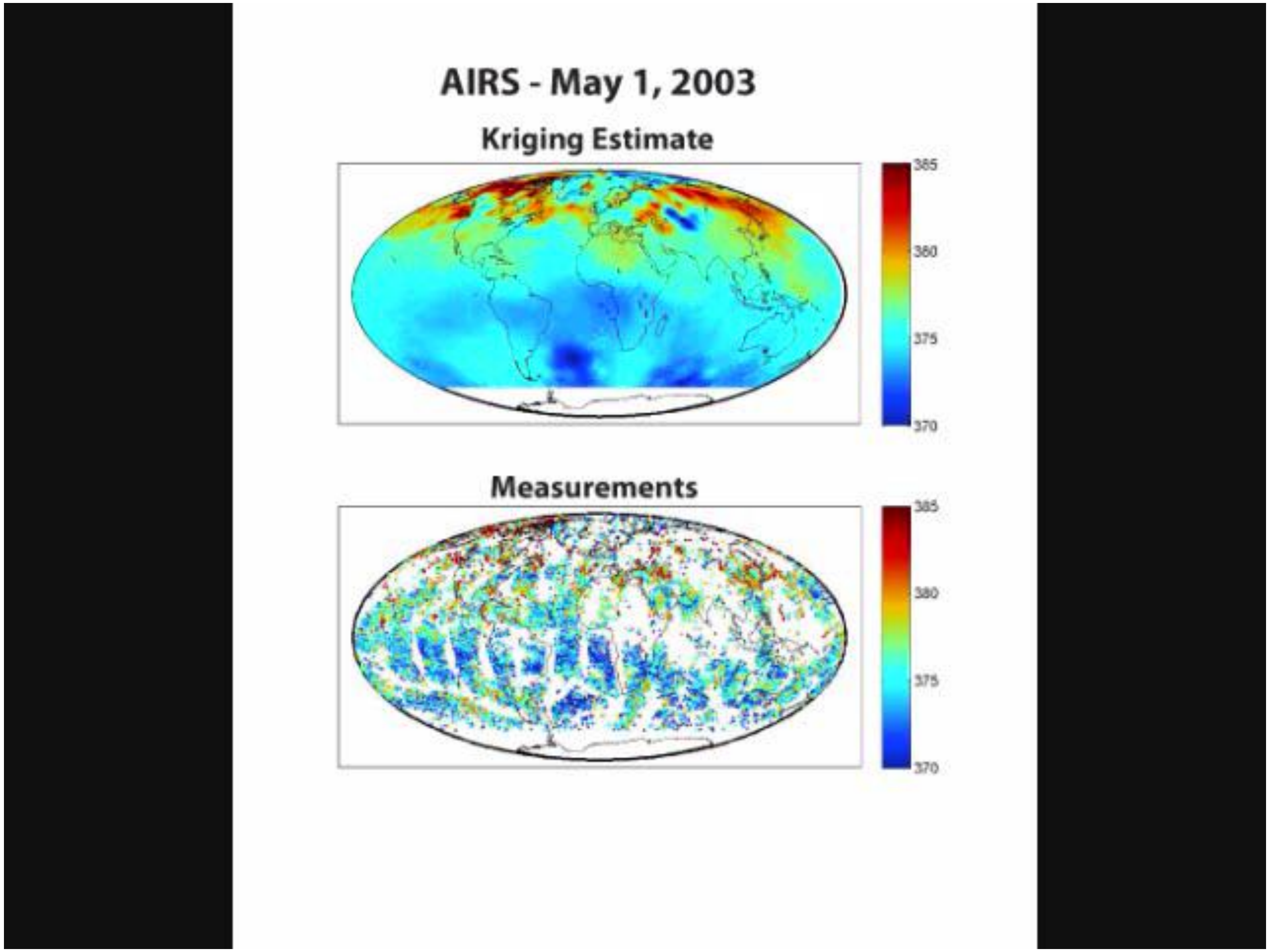
(Low CO2 in Central Pacific)

+1.56 ppm

-1.00 ppm

AIRS CO_2 anomaly difference
(El Nino – La Nina)
(Consistent with change in Walker Circulation)

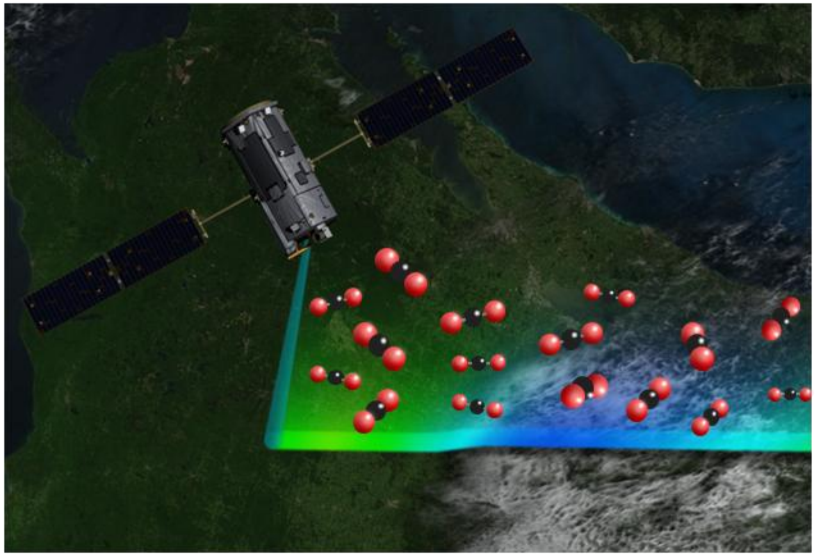
Jiang, X., M. T. Chahine, E. T. Olsen, L. L. Chen, and Y. L. Yung (2010), Interannual variability of mid-tropospheric CO2 from Atmospheric Infrared Sounder, Geophys. Res. Lett., 37, L13801, doi:10.1029/2010GL042823



Source: Dorit Hammerling and Anna Michalak

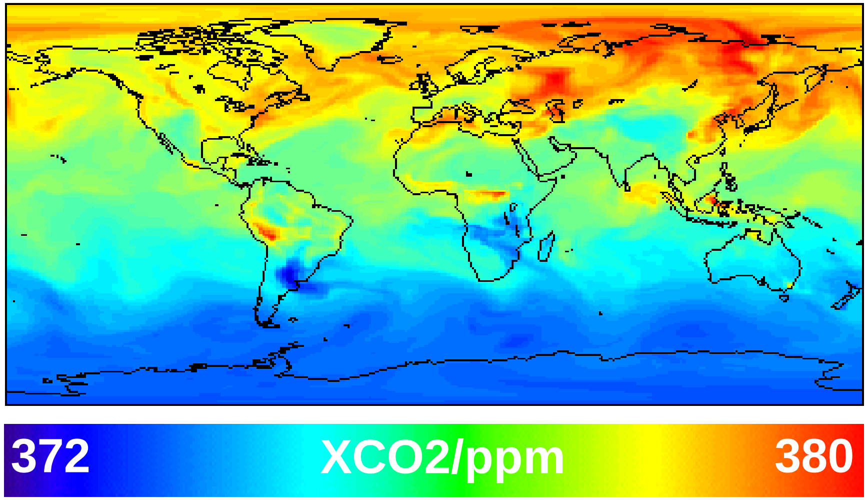
The Orbiting Carbon Observatory (OCO-2)

NASA's Orbiting Carbon Observatory (OCO) was designed to return space-based measurements of atmospheric carbon dioxide (CO_2) with the sensitivity, accuracy and sampling density needed to quantify regional scale carbon sources and sinks and characterize their variability.



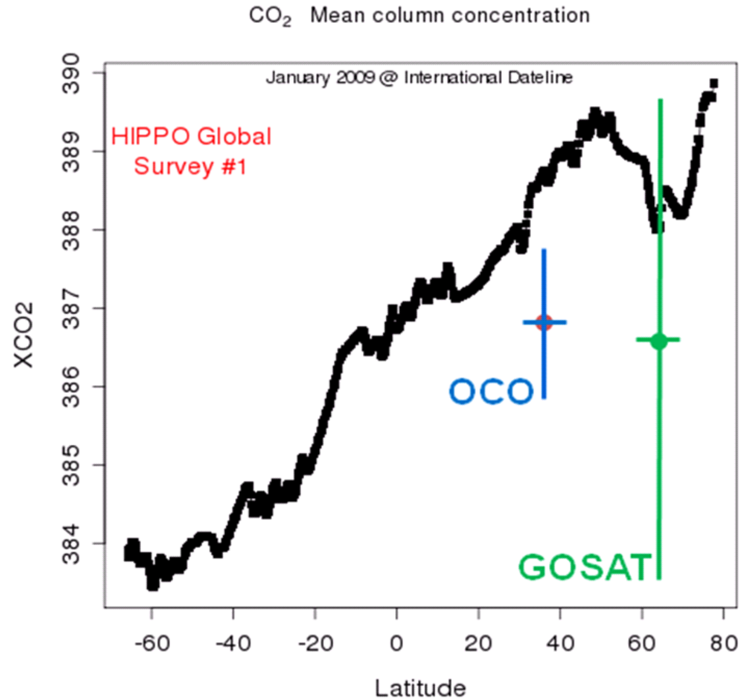
- Collects up to 1,000,000 (10^6) soundings over the sunlit hemisphere each day
  - Single sounding precision of 1 ppm (< 0.3% of 389 ppm background) for both oceans and continents over the sunlit hemisphere
  - 3 sq km footprint (at nadir) enhances sensitivity to point sources and probability of collecting cloud free soundings

Measuring CO2 from Space Requires High Precision



XCO2 Simulation: J Randerson

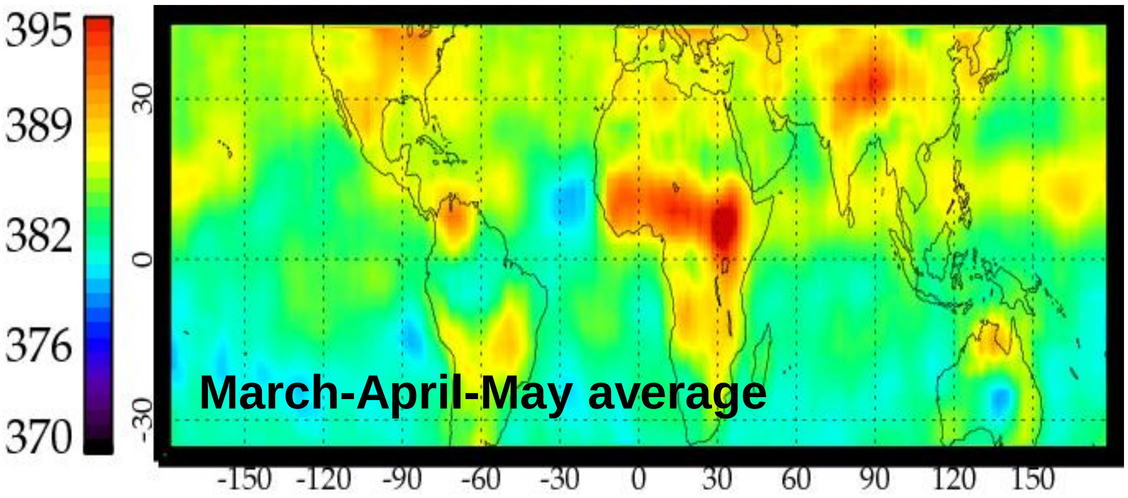
- CO_2 sources and sinks must be inferred from small spatial variations (~1 ppm) in the background CO_2 distribution (>380 ppm)

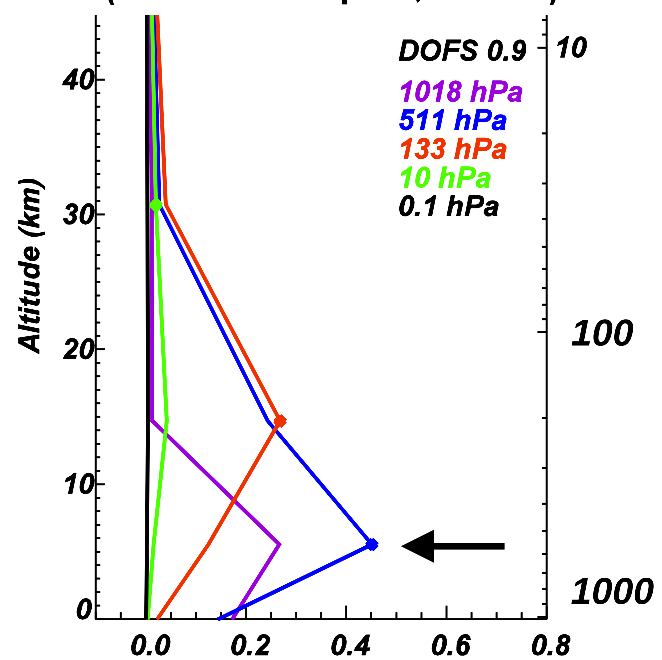


Real pole-to-pole changes in X_{CO2} show detailed structure and abrupt changes.
Compare to the precision targets for OCO-2 and GOSAT

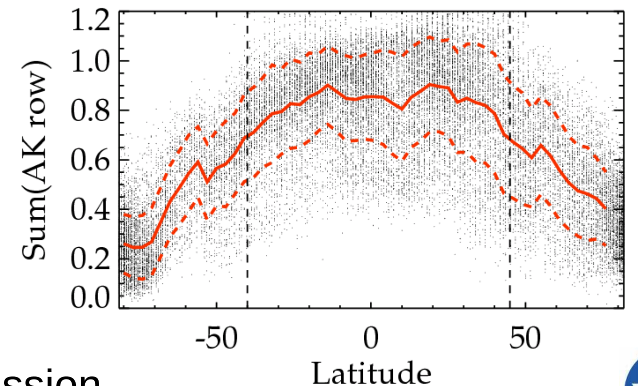
NSF HIAPER aircraft campaign data
(S. Wofsy, private communication, 2009).

Tropospheric Emission Spectrometer (TES) CO_2





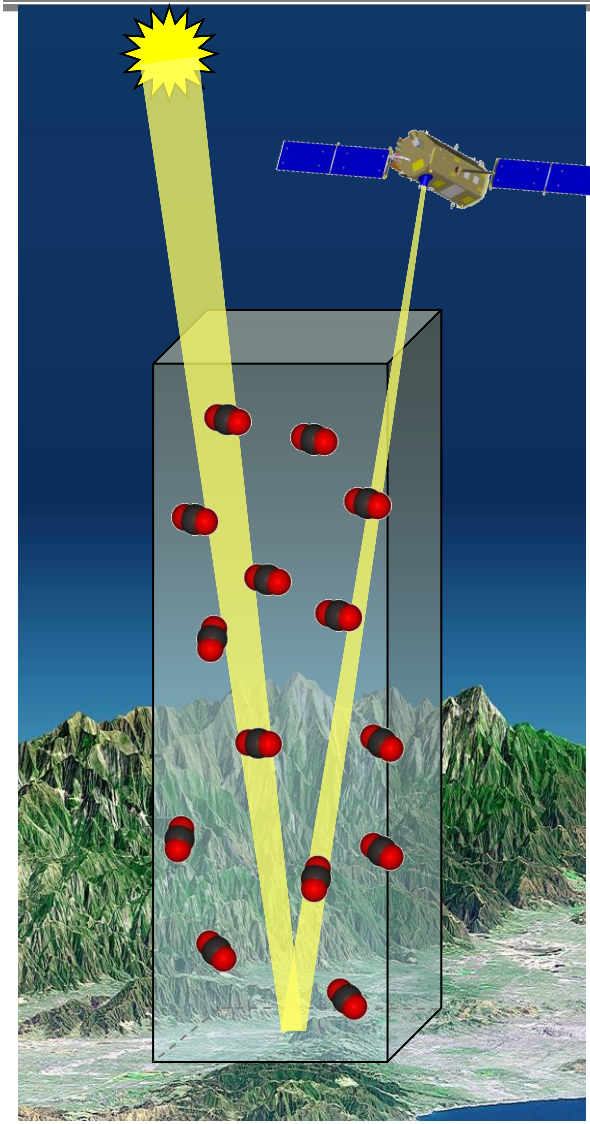
- CO_2 retrieval uses 670-725, 970-990, and 1070-1120 cm^{-1} spectral regions
- T_{atm}, H_2O, CO_2, cloud parameters and surface temperature are co-retrieved
- Vertical sensitivity of the retrieval to CO_2 in the atmosphere is given by the averaging kernel matrix
- Peak sensitivity found at 511 hPa ~40° S-40° N
- Small footprint (5.3 x 8.3 km^2) helps avoid clouds

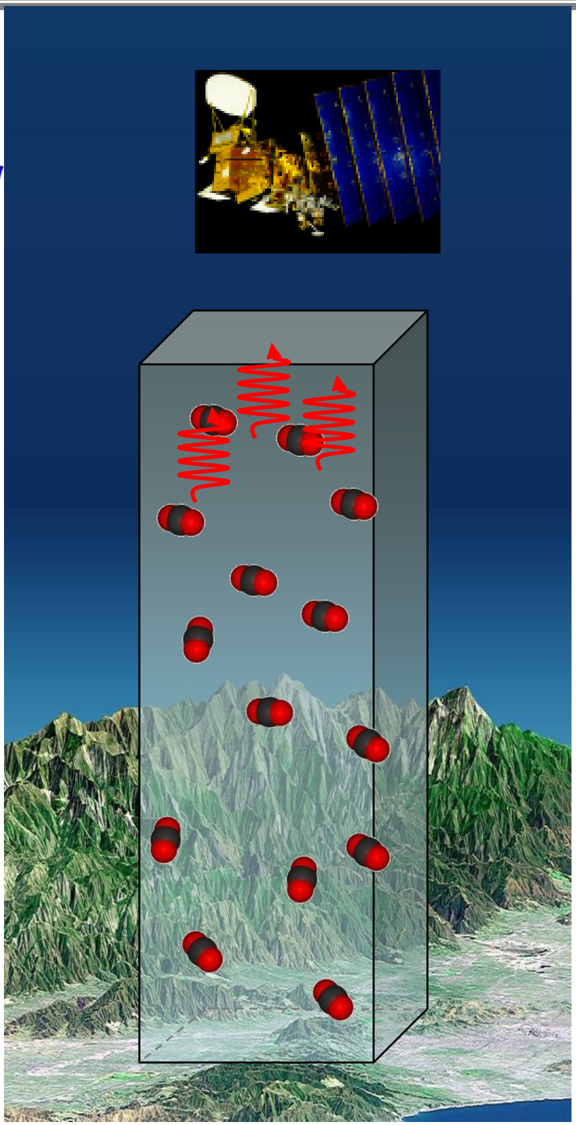


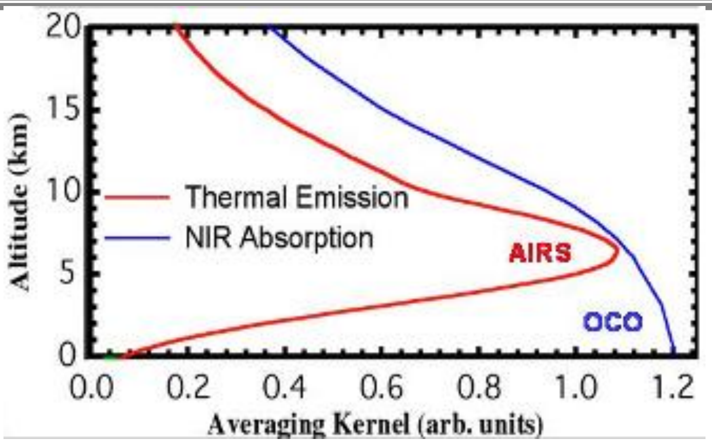
Kulawik et al. (2010), Characterization of Tropospheric Emission Spectrometer (TES) CO_2 for carbon cycle science, ACP

[Susan Kulawik]

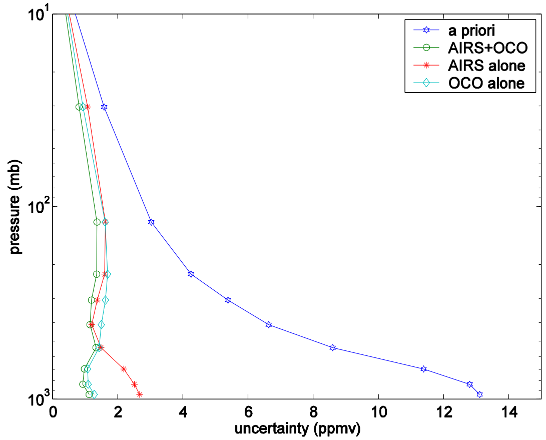
Combining OCO-2, AIRS and TES Yields New CO2 Data Products







Averaging kernels for detection of atmospheric CO_2 for OCO (blue) and AIRS (red). OCO and AIRS information can be combined to yield vertically resolved CO_2 profiles.



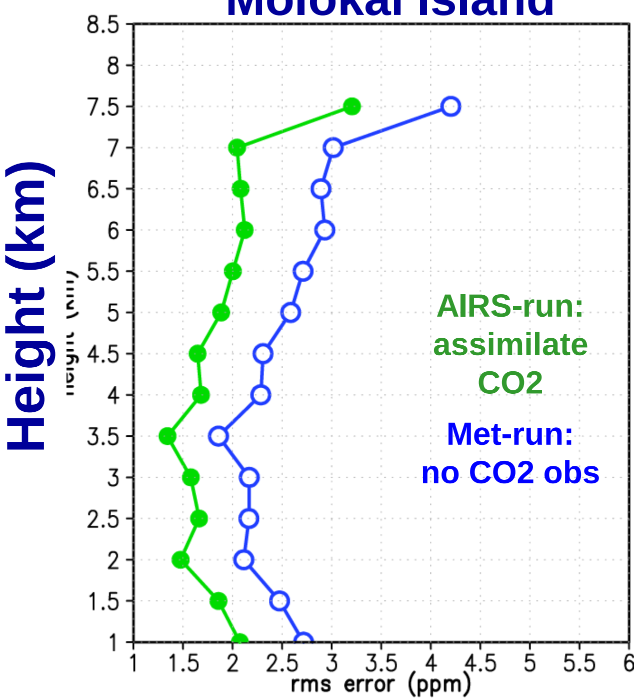
Assimilation of AIRS CO_2 observations improves CO_2 spatial distribution and the accuracy of CO_2 vertical profiles

(Junjie Liu- UC Berkeley)

AIRS-run: simultaneously assimilate AIRS CO_2 + meteorological observations with EnKF in a carbon-climate model;

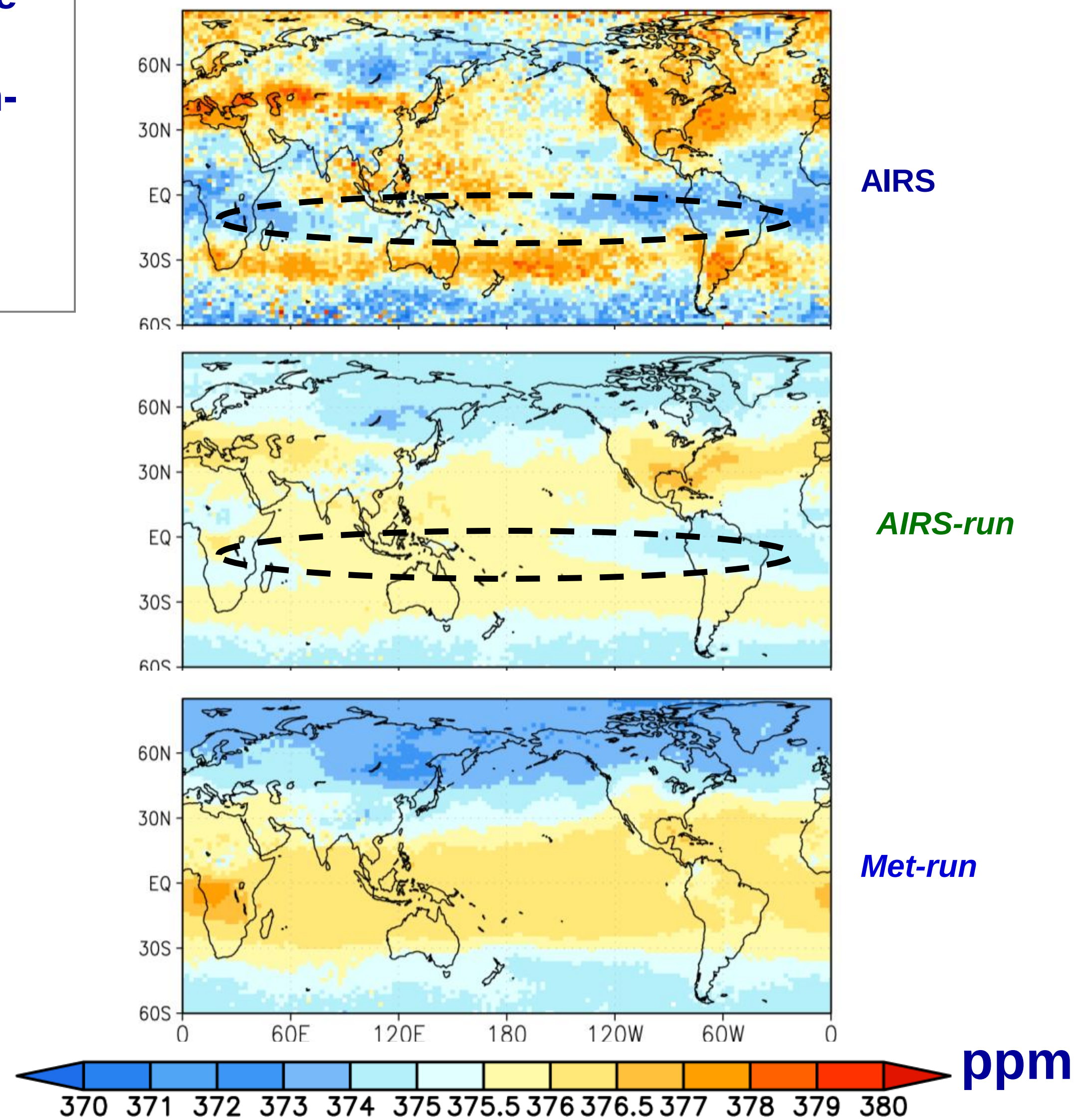
Met-run: only assimilate meteorological observations;

Molokai Island

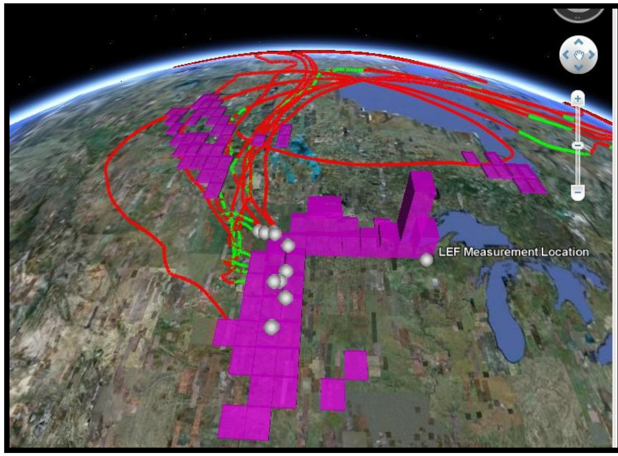


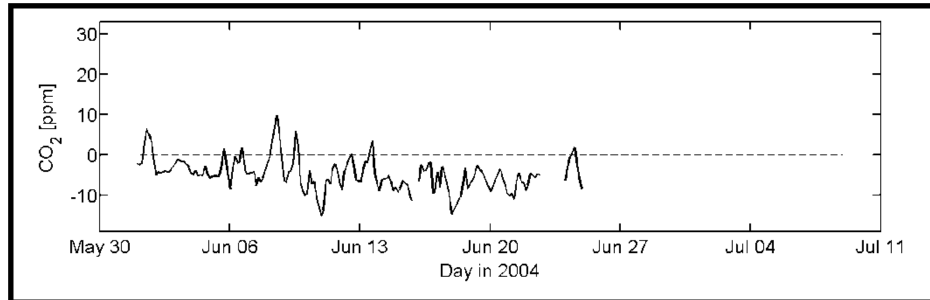
Verify against independent aircraft observations

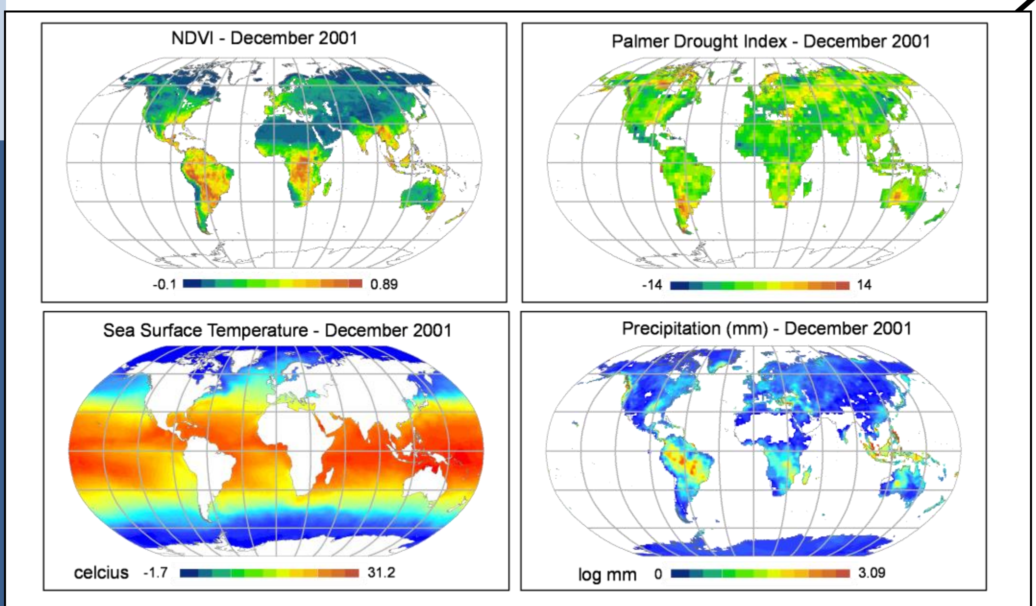
Column-integrated CO_2 in August



Atmospheric Inversion Model







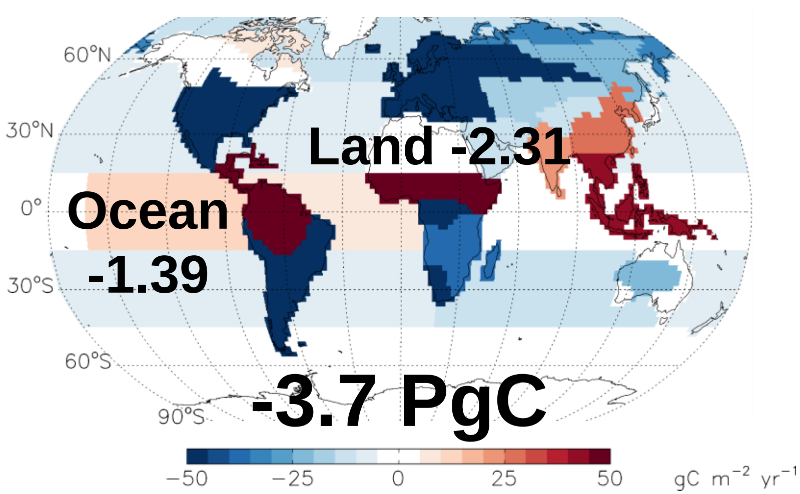
Inversion

Carbon Budget

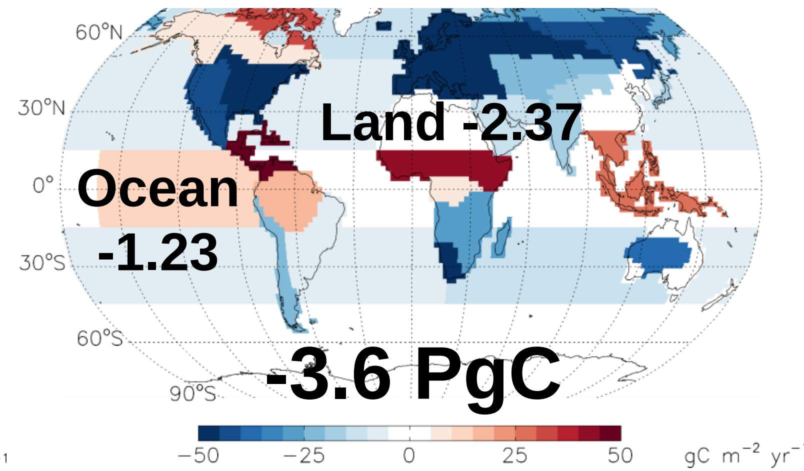
ε

Comparison of Inversion Results (2006)

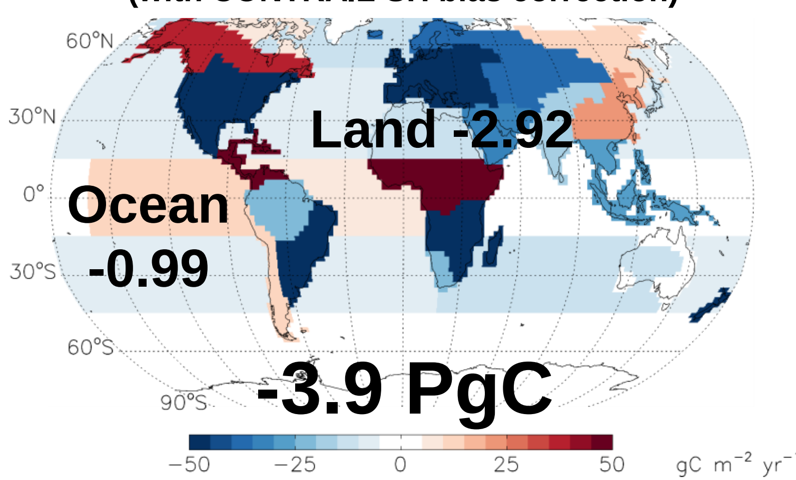
A Priori



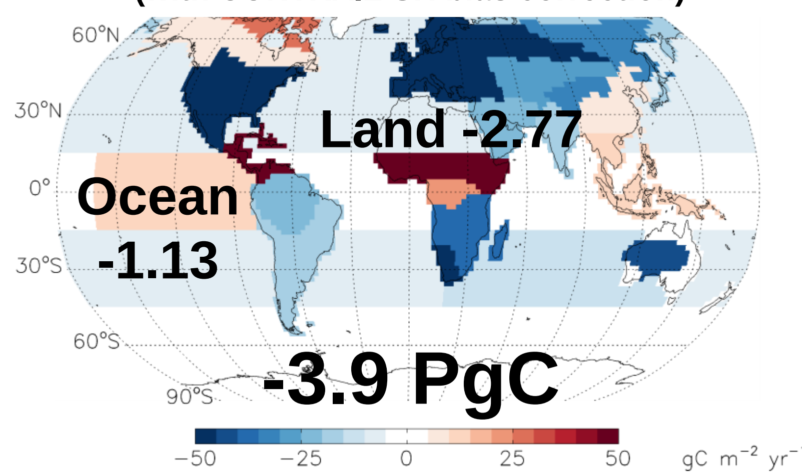
Flask inversion (59 Locations)



TES inversion
(with CONTRAIL SH bias correction)



Flask + TES inversion
(with CONTRAIL SH bias correction)



CarbonTracker-EU: Global -3.9, Ocean -2.34, Land -1.60 PgC
MPI-Jena: Global -4.0, Ocean -0.51, Land -3.45 PgC

[Ray Nassar, Dylan Jones]

Summary

- Understanding natural components of carbon cycle is critical to understanding future climate
- Ability to quantify / verify anthropogenic carbon emissions is required for effect carbon management
- A-Train measurements, including those from MODIS, TES, AMSR-E, OCO-2, and AIRS, are contributing to carbon cycle science by providing:
  - Remote sensing observations of ecosystem structure and dynamics
  - Process understanding and integration into models
  - Observations of atmospheric carbon gases
  - Model / atmospheric data integration and inverse models